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A UNIVERSITY DESIGN STUDY OF PROTECTION FACTORS IN TYPICAL AMERICAN HOUSES

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FINAL REPORT

A UNIVERSITY DESIGN STUDY OF PROTECTION FACTORS IN TYPICAL AMERICAN HOUSES

by

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ABSTRACT

Measurements were made of the ground contribution to the reduction factor at several locations in several typical American houses. Comparisons are made between experimental results and Engineering Manual calculations for the various locations. Comparisons are also made between different houses to observe the effects of changes in structural parameters, such as variations in exterior wall mass thickness.

In general, Engineering Manual results agree well with experimental results in the first story measurements of the ground contribution. The agreement for basement measurements seems to be a function of the location and elevation of the point in question. Agreement is good for locations in the lower half of the basement. However, as the locations approach the basement ceiling experiment and calculations may disagree by as much as a factor of two or three for the ground contribution. The calculations are usually on the conservative side when discrepancies are noted.

The Engineering Manual predicts a steady increase in the reduction factor as the detector location is moved toward the basement ceiling along the vertical centerline of the test structure. This trend was not observed experimentally. The reduction factors showed a weak dependance on the elevation in the lower half of the basement and displayed a significant decrease as the basement ceiling was approached.

Four types of Engineering Manual Calculations were performed for the purpose of comparison; a ^{60}Co energy spectrum was used in conjunction with Eisenhauer's floor attenuation factor and the usual floor barrier reduction factor; the same calculations were performed using a 1.12 hour fission product spectrum. It was found that the energy spectrum made little difference for above grade calculations, but significant differences were noted below grade.

ACKNOWLEDGEMENTS

The authors are indebted to Dr. William R. Kimel under whose direction the Kansas State University Nuclear Engineering Shielding Facility was created and under whose leadership this work was begun, to Mr. Charles Eisenhauer for his suggestions during the course of the work, to Mr. Ray E. Hightower for his assistance in both administrative and technical support, to Mr. R. M. Rubin for his assistance in the far-field calculations, and to Dr. L. V. Spencer and Dr. A. B. Chilton for many helpful discussions.

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I. INTRODUCTION

The specific objective of this work was the experimental measurement of reduction factors in the basement of several typical full scale American houses situated in a simulated infinite plane fallout field.

The test structure was a typical 30' x 40' house with special design features which allowed the variation of the exposed basement wall height, exposed basement wall mass thickness, exterior wall mass thickness, and the interior partition configuration. All the apertures and ground floor entrances were placed in symmetrical positions which allowed the plane fallout field to be simulated in only one quadrant of the field. The plane source was simulated by a ^{60}Co pumped source circulation system. The source was pumped through polyethylene tubing arranged in quarter annular areas centered on and extending from the center of the test house to a radius of 169'. Measurements were made in a grid pattern in the basement which, after symmetry consolidations, results in data at seven points in one quadrant of the basement at two different elevations. In addition, measurements were made at one-foot intervals along the vertical basement centerline and the first story vertical centerline. The upstairs detectors were never moved with respect to ground level. The basement detectors, however, were raised and lowered with the floor panel in order to maintain constant solid angle fractions subtended by the floor.

The broad objective of this work was to provide experimental data for comparison with results of theoretical structure shielding analysis. In addition, the data could be used to specifically indicate the weak points and the strong points in the analysis methods currently in use.

Current methods in structure shielding analysis are based largely on the work of Spencer and Eisenhauer (1-3). Basic data provided by Spencer on the penetration of gamma rays through barriers have been used by Eisenhauer to develop geometry factor and reduction factor design curves which have found wide use in the "Engineering Manual" method of structure shielding analysis (4).

Many assumptions and approximations were necessary in the development of the design curves used in the Engineering Manual. Several experiments (7-13)

have been done to try to determine the validity of the necessary assumptions and/or to try to make specific recommendations as to proposed modifications. Most of these experiments however, were scale model studies or "simple structure" studies which have not adequately covered the range of possible variables for typical residential type structures.

The data are reported in the form of reduction factors with associated 68 percent confidence limits. The raw data were corrected for temperature and pressure variations and normalized to a standard dose rate of 480 R/hr per Ci/ft^2 (6).

The experimental procedure and facilities are described in detail in Section II. The experimental work was under the direct supervision of Mr. Roger S. Reynolds. Support work in far field contribution studies, Engineering Manual calculations, generation of ^{60}Co design curves, and computer programming were carried out jointly by Messrs. Charles A. Burre, Richard M. Rubin and Roger S. Reynolds.

II. THE EXPERIMENTAL STUDY

2.1 Introduction

The specific goal of the experimental study was to measure the reduction factors at several locations in twenty typical American houses for a simulated infinite plane source of fallout radiation. In this section experimental facilities and methods are discussed in detail. Experimental results and comparisons are discussed in Section IV.

2.2 Description of Facilities

2.2.1 The Test House

The experiments were conducted at the Kansas State University Nuclear Engineering Shielding Facility (KSUNESF). The Facility is a 180-acre plot of land located 5 miles west of Kansas State University. It is accessible, yet isolated as required for radiation shielding studies.

The test structure, shown in Figure 2-1, is a 30' x 40' "typical" American house, with a full basement. The term "typical" applies to the size and the construction materials used in the structure. The overall design, however, is unique in that several houses may be simulated by making various physical changes in the actual structure (shown schematically in Figure 2-2).

The most unusual feature of the test structure is the floor panel. The floor is a stressed skin sandwich panel detached from the house itself and supported by jack posts located in the basement. This allows a great deal of flexibility in that any extent of exposed basement wall between 0 and 3 feet may be simulated by raising or lowering the floor panel on the jack posts. The panel itself is a very rigid structure and no noticeable deflection can be observed across the entire test structure when the floor panel is supported at eight places around the edges.

Concrete blocks stacked around the perimeter allow the simulation of various mass thicknesses of the exposed basement wall. At the present time the capabilities are 5.5 psf with no blocks, 45.5 psf with one course of blocks, and 85.5 psf with two courses of blocks. These variations encompass most of the values of interest encountered in typical residential problems in structure shielding.

Precast concrete panels are available at the KSUNESF for use in simulating brick veneer construction for the exterior walls. With no panels in place, the exterior wall mass thickness is 5.5 psf. When the panels are installed a 45.5 psf exterior wall results. Again, these values satisfactorily encompass the range of values usually encountered in typical residential structures.

In addition to the above capabilities, wood frame partitions are available for simulating room layouts inside the structure in order to observe the effects of interior partitions on the reduction factors. At present this capability exists for floor heights of 0 and 3 feet.

The mass thicknesses of the construction materials used in the test house were determined experimentally by taking random samples of the actual materials and measuring the mass thickness in pounds per square foot (psf). Fallout simulation areas, Figure 2-3, were graded to a slope of 1.5 percent to a radius of 200 feet. Tubing extended out to 169 feet, however, and the remaining area was used as a drainage table.

Figures 2-4 through 2-22 are detailed drawings of the test house, the exterior wall panels and the basement exposure blocks.

2.2.2 Detectors

2.2.2.1 10 mR Ionization Chambers

Ionization chambers were used in the experiments when the exposure in the structure was less than 10 milliroentgens (mR). This was generally the case in the second and third tubing areas for basement measurements. The chambers used were Victoreen Model 239 stray-radiation chambers, 4.5 inches long, 2 inches in diameter, with a bakelite wall thickness of 1/16 inch. The detectors were used in conjunction with a Technical Operations, Inc. charger-reader, designed for the Victoreen chambers.

2.2.2.2 Thermoluminescent Dosimeters (TLD)

The TLD were used in the experiments when the exposure was in excess of 10 mR. This generally occurred in the first area basement measurements and in most of the upstairs measurements. The dosimeters used were CaF_2:Mn, manufactured by Edgerton, Germeshausen and Grier, Inc., (EG&G) model TL-12. The TLD is a wide range gamma device capable of measuring total exposures in

the range from about 1 mR to 50,000 R. The overall dimensions are 1.68 inches long by 0.40 inches in diameter. The TLD were used in conjunction with an EG&G reader which provides a permanent strip chart readout calibrated in mR.

2.3 Experimental Methods

2.3.1 Plane Source Simulation

A plane source of fallout was simulated by ^{60}Co sources using a hydraulic source circulation system.

The source circulation system (Tech/Ops. Model 539) consists basically of five components: the ^{60}Co source, the source storage container (a 2,200 pound lead pig), the hydraulic reservoir, the pump console, and the polyethylene tubing. Approximately 15,000 feet of tubing were used. The tubing was Union Carbide type DFD-0600 with 0.25 percent American Cyanamid UV531 ultraviolet inhibitor. The tubing dimensions are 5/8 inch outside diameter and 3/8 inch inside diameter. Sources were calibrated using a Victoreen model 570 R-meter calibrated by the National Bureau of Standards. During calibration, both the source and meter were suspended from 50 foot towers at the KSUNESF.

2.3.2 Quality Control

A quality control program is necessary in order to insure predictable operation of the dosimeters. The ionization chambers are very sensitive to moisture and dust. If the dosimeters have accumulated dust or moisture the readings may be off scale or unstable. Consequently the chambers were baked out at 100° F. at regular intervals, which is the manufacturers recommended procedure. In addition, the dosimeters were encased in plastic "freezer" bags to minimize the dust problem. When cleaning was necessary acetone was used. A heavy duty dehumidifier was also placed in the basement of the test structure.

The TLD are insensitive to dust, moisture, and normal outside temperature changes. However, a thermoluminescent device does accumulate a residual dose after extended use. This has the effect of reducing the sensitivity in the lower exposure ranges (less than 5 mR) and building up a high temperature "tail" which affects the primary-peak readings. This residual dose can be removed by annealing the dosimeters at 350°C for approximately 30 min. This procedure

was adopted and the TLD were annealed in this manner when the accumulated exposure was in the vicinity of 150 mR. After very long use, nominally 100 reader cycles per dosimeter, permanent damage results which cannot be removed by the suggested annealing procedure. In this case the dosimeters were annealed at 350°C for about 8 hours and were not subsequently used in cases where the exposure was less than 5 mR.

The TL-12 dosimeters also accumulate a background dose of about 1 mR per day due to the bonding material used in the device. This is easily removed by a reader cycle or a brief oven bakeout procedure, and must be done before each experiment.

In addition to the precautionary measures discussed the calibration data for all of the detectors were checked at regular intervals to make sure no long term changes were taking place. Some small changes were noted in the TLD data after the rather severe 8 hour annealing. The calibration procedure is discussed in detail in Appendix C.

2.3.3 Test Parameters and Detector Locations

Table 2-1 is a list of the experiments and the variable parameters corresponding to a particular test. There were two major categories in the test sequence: thin wall cases (X_e = 5.5 psf) and heavy wall cases (X_e = 45.5 psf). Within each category there were variations in extent of exposed basement wall and in the mass thickness of the exposed basement wall. The notation of "partitions in place" refers to a standard nine compartment grid layout on the first floor (Figure 2-6).

The detector locations are shown in plan in Figure 2-23. The grid shown was chosen to facilitate interpolation of data or theoretical calculations if necessary or desired. Each quadrant in the basement is symmetrical with respect to any of the other quadrants. Such a grid was necessary in order to do quarter symmetry measurements. The detector locations are shown in elevation in Figure 2-24 for the four floor heights used in the experiments. The grid locations shown in Figure 2-23 (other than the center one) are placed at two elevations as shown in the off center locations in Figure 2-24. Basement and upstairs centerline data were accumulated at the positions indicated. It should be noted that the solid angle fractions for the basement detectors remain constant.

The quarter symmetry consolidations result in the final grid pattern shown in Figure 2-25. The grid point numbers are used to facilitate reference to the reduced data shown in Section IV. The numbers and the grid height uniquely determine the position of interest in the test structure.

2.3.4 Data Acquisition and Analysis

The experiments were designed to provide reproducible results while economizing the time required. Data were accumulated at each of the locations for each of three areas. At least three source runs were performed successively for each area. An effort was made not to place the same dosimeter at the same location in successive runs. After each source run the dosimeters were read out and simultaneously zeroed which prepared them for the next run.

The chamber data were read out and immediately recorded since no permanent record of the exposure is available with the system used. The TLD were read out and the strip charts filed and recorded appropriately. All of the data were eventually put on punched cards for digital computer processing using the IBM 360/50 system at the Kansas State University Computing Center.

There are two major steps in the data analysis: (1) reduction of the raw dosimeter data to calibrated results, and (2) reduction of the calibrated dosimeter data to meaningful grid point location results. These two steps are performed in two computer codes written for that purpose. The first step is performed using a code called DATARED which applies the dosimeter calibration data to the raw input data, makes the necessary temperature and pressure corrections to the chamber readings, and normalizes the data to a standard exposure rate of 480 R/hr per Ci/ft^2. As these calculations proceed the appropriate 68 percent confidence limits are also calculated for each dosimeter reading.

The second step is performed by a code called DATASUM. Punched output from DATARED and some additional control information are used as input to DATASUM. DATASUM averages the area data, calculates the far-field contribuition, performs the symmetry consolidation and finally yields the experimental ground contribution reduction factor by the usual superposition technique. The calculation of the far-field contribution is discussed in Appendix E.

TABLE 2-1

Parameter Variations for Test Houses

X_f = mass thickness of first floor = 12.0 psf.

h = height of top of floor panel above grade, ft.

X_e = exterior wall mass thickness, psf.

X_w = exposed basement wall mass thickness, psf.

House	h	X_e	X_w	Partitions
1	0	5.5	-	None
2	1	5.5	45.5	None
3	1	5.5	85.5	None
4	2	5.5	85.5	None
5	2	5.5	45.5	None
6	3	5.5	45.5	None
7	3	5.5	85.5	None
8,9	3	5.5	5.5	None
10	3	5.5	45.5	In Place
11	0	5.5	-	In Place
12	0	45.5	-	None
13	2	45.5	45.5	None
14,16	2	45.5	85.5	None
15	1	45.5	45.5	None
17	3	45.5	85.5	None
18	3	45.5	45.5	None
19	3	45.5	45.5	In Place
20	0	45.5	-	In Place

The 68 percent confidence limit associated with the final result includes the following errors: (1) random error encountered in the calibration of the dosimeters, (2) random error associated with each source run, (3) least squares error encountered in the evaluation of the far-field contribution, and (4) the systematic error associated with the source strength of the ^{60}Co source used.

III. THEORETICAL CALCULATIONS

3.1 Introduction

This section describes the methods used in the calculation of theoretical reduction factors in the test house, as well as the method employed in calculating the far field contribution to the measured reduction factors. Engineering Manual (EM) calculations were performed using the floor barrier reduction factor as published in the July 1968 edition of TR-20 and using the attenuation factor developed by Eisenhauer, as published in the 1969 edition of TR-20. The calculations were done for an energy spectrum representing fallout as well as for ^{60}Co.

3.2 Engineering Manual Detailed Procedure

Several approaches were used to obtain estimates of the theoretical reduction factors in the test house: (a) hand calculations using TR-20 Vol.1, (b) the CAPS-2 computerized method (16), (c) the Home Fallout Protection Survey (HFPS) computerized method (17) and (d) a computerized method developed and designed specifically for the KSUNESF structure.

The hand calculations were valuable in estimating the range of values that might be expected in the theoretical calculations. It was found however that significant variations occurred in the results because of various interpretations possible in the charts. This fact coupled with the economics of performing many calculations yielded to method (d) above.

CAPS-2 is based on the computational techniques and charts in PM-100-1 "Design and Review of Structures for Protection from Fallout Gamma Radiation," specifically the detailed procedure from the Engineering Manual. Disagreement between CAPS-2 and hand calculations will arise from two major areas, the accuracy obtainable in reading the charts in the Engineering Manual, and the fact that input to the CAPS-2 computer code is limited to fixed incremental values of the design parameters. In the particular case of the KSU test structure the aperture height is 7.5 feet while the nearest input available in CAPS-2 was 7.0 feet. In the thin-walled cases this would have the effect of raising the CAPS-2 reduction factors because more scattering surface is available.

The HFPS system uses 3 standard houses with various construction materials to calculate protection factors via a "table look-up" technique. The KSU test structure was compared with the type I home for the construction materials reported. The reduction factors are expected to be higher for the HFPS calculations because of the conservative nature of the method. In addition to the conservative nature of the HFPS technique, reduction factors are only available at the center of the basement and in the "best" corner, consequently few comparisons are realized as opposed to the CAPS-2 results where all of the KSU detector locations may be calculated explicitly.

A computer program, ENGMAN, was written at KSU to calculate economically and rapidly, reduction factors of interest and to have a consistent set of results available for comparison. Tabulated Engineering Manual charts were available (5) for use in the code and linear interpolation was used to obtain values not specifically listed. A detailed description of the functional expressions used and the methodology employed are given in Appendix A. Mr. J. L. Dirst of OCD provided KSU with CAPS-2 calculations for Test 1 at the standard grid point locations shown in Figure 2-25. In this investigation, only the ground contribution to the reduction factors in the test structure were of interest, consequently the input to CAPS-2 specified an infinite overhead mass thickness in order to eliminate the roof contribution. Unfortunately, this also eliminated the skyshine contribution through the roof. If this contribution is subtracted from the KSU calculations the agreement between CAPS-2 and the KSU calculations is very good, as indicated in Table 3-1. It is felt, therefore, that the KSU calculations are consistent and representative of the best Engineering Manual predictions available.

In addition to the ENGMAN capability just discussed, Engineering Manual design charts for a ^{60}Co energy spectrum were developed (Appendix B) for the parameters of interest in this work. Therefore, Engineering Manual type calculations may be done for the actual fallout simulation spectrum used.

3.2.1 Floor Barrier Reduction Factors

ENGMAN has the option of using either of two forms of the floor barrier reduction factor for either of the two energy spectra possible. One option uses the usual form, $B_c(X_c)$ as published in the July, 1968 edition of TR-20 Vol. 1.

TABLE 3-1

Comparison of CAPS-2 and KSU
Engineering Manual Calculations
for House 1

Grid Pt. Number	Height	CAPS-2	KSU*	KSU**
1	3'	.0078	.0072	.011
2	3'	.0086	.0090	.012
3	3'	.012	.013	.018
4	3'	.011	.012	.017
5	3'	.0069	.0081	.0093
6	3'	.013	.013	.018
7	3'	.012	.013	.017

* Without roof skyshine component
** With roof skyshine component

Eisenhauer (14) has proposed a new barrier factor which depends on the solid angle fraction subtended as well as the overhead mass thickness, $B_o'(X_o',\omega)$. This barrier factor is used in the July, 1969 edition of TR-20. $B_c(X_c)$ is well known and its use will not be discussed here.

Eisenhauer's formulation is an attempt to more accurately represent the "in-and-down" contribution to the exposure rate in the basement and is based on an optimization of agreement with experimental attenuation in the basement ceiling, rather than an optimization with the experimental reduction factors. The detailed points of the philosophy and reasoning behind the recommended correction are discussed in (14). The functional form suggested is shown below in equations (3.1) and (3.2) for the two energy spectra of interest.

$$B_o'(X_o',\omega) = (1-3.5\ e^{-2.3\omega})\ e^{-0.10X_o'} + 3.5\ e^{-2.3\omega}\ e^{-0.040X_o'} \quad (3.1)$$

$$B_o'(X_o',\omega) = (1-3.0\ e^{-2.3\omega})\ e^{-0.12X_o'} + 3.0\ e^{-2.3\omega}\ e^{-0.042X_o'} \quad (3.2)$$

Equation (3.1) is for a fallout energy spectrum and (3.2) is for a ^{60}Co energy spectrum.

3.3 Far Field Contributions

For obvious reasons, experimental work is performed using finite area sources rather than infinite area sources. Since the results must be compared with calculations based on an infinite plane source, the contribution from the plane not simulated to infinity must be evaluated and added to the finite plane source measurements.

A method proposed by Kaplan (15) was used to evaluate the far field. This method treats the skyshine and non-skyshine components separately in the analysis. A brief outline of the method is presented below, and details are given in Appendix E.

Since the angular distributions of the skyshine and non-skyshine components of the total dose rate in the test structure are significantly different it is necessary to treat them separately in the estimate of the far-field contribution. First the free-field dose rates are defined as:

S_n = skyshine free-field dose rate at the center of the annulus from the nth source annulus,

D_n = non-skyshine free-field dose rate at the center of the annulus from the nth source annulus.

Then two structure attenuation coefficients α_S and α_D are defined which are the skyshine and non-skyshine structure attenuation coefficients. If R_n is the measured exposure rate in the center of the test structure for the nth source annulus, it follows that

$$\alpha_D D_n + \alpha_S S_n = R_n \qquad (3.3)$$

where R_n is the measured exposure rate in the test structure.

The free field exposure rates were calculated for each source annulus and the far field using moments method calculations (18). The structure attenuation coefficients were evaluated using a least-squares technique.

The least-squares analysis of equation (3.3) is based on the assumption that subtracting R_n from the right and left side of the equation should yield zero. Since this is in general not true because of the usual experimental errors involved in the measurement of R_n and the possible errors involved in the evaluation

of the free-field dose rates, the approach of minimizing the squared error with respect to the structure attenuation coefficients is taken. This then yields expressions for the structure attenuation coefficients.

If the assumption is made that α_D and α_S do not change with distance from the test structure, equation (3.3) can then be used to calculate R_f, the far-field exposure rate in the test structure, based on S_f and D_f, the free-field exposure rates for the far-field.

IV. EXPERIMENTAL RESULTS

4.1 Introduction

The experimental results are presented in tabular form as a function of grid height and grid point number. The key to the gridpoint locations is shown in Figure 2-25, a zero grid point number indicates upstairs centerline data. All other grid points represent basement detector locations. In addition to the experimental results, four different types of EM calculations were performed for the purposes of comparison. These theoretical results are shown along with the experimental results in the same format. The associated standard deviations for the experimental results and the estimated far-field contribution are shown immediately below each data point in the tables; i.e., the reduction factors are double spaced with the standard deviations located between the lines.

The experimental data are presented in Tables 4-1 through 4-15. Each table consists of five columns of reduction factors. The first four component reduction factors are for source areas 1, 2, and 3 and the far field. The last column is the total experimental reduction factor and is the sum of the first four columns. Theoretical results are presented in Tables 4-16 through 4-33. Each table consists of five columns, the first four columns are various types of EM calculations which are clearly indicated on each table. The fifth column is the total experimental reduction factor and its standard deviation. The Engineering Manual calculations will be described in the following manner for purposes of brevity: EM 1 is the detailed procedure calculation using a ^{60}Co energy spectrum and the floor barrier reduction factor $B_c(X_c)$, EM 2 is the same calculation using the 1.12 hour fission product spectrum, EM 3 is a detailed procedure calculation using a ^{60}Co energy spectrum and Eisenhauer's modified floor barrier reduction factor $B_o'(X_c, \omega)$, and EM 4 is the same calculation using the 1.12 hour fission product spectrum.

4.2 Discussion of Results

Two major categories of comparison are possible with the data presented. One comparison may be made with the EM calculations to check the accuracy of the theoretical predictions. A second comparison may be made between various

test configurations in order to determine the relative magnitude of changes in exposure rates due to isolated parameter changes.

Examine first the change in experimental reduction factors when partitions are installed in the test structure. Houses 1 and 11 are identical except that House 11 has a nine compartment interior partition grid in the first story (see Figure 2-6) where House 1 has no partitions. Figure 4-1 shows the experimental results as a function of height above the basement floor in the center of the basement. There does not seem to be a significant difference in the results. The same holds true in general for the off center locations in the two Houses. The effect of the interior partitions was neglected in the basement calculations performed with the KSU computer code ENGMAN and the results indicate that this approximation is a reasonable one, at least for the "thin" partitions used in this work. The same conclusions may be drawn from an inspection of the data for Houses 6 and 10, where the agreement is even more distinct as evidenced in Figure 4-2.

Figure 4-2 also shows the corresponding EM calculations for Houses 6 and 10. Agreement is fair at the lowest position on the centerline of the basement, but theory and experiment diverge from that point. A marked increase is predicted by an EM calculation but no increase is observed at the below grade positions. At the grade position, a difference of 100 percent is noted.

In order to see the effect of changing the exterior wall mass thickness a comparison of Houses 1 and 12 is appropriate. The two houses are identical except that X_e for House 1 is 5.5 psf and is 45.5 psf for House 12. Figure 4-3 is a plot of the basement centerline data for the two configurations. The results indicate that the two structures provide an essentially equal amount of protection. The same result is predicted by the various EM calculations. Figure 4-4 shows the effect on the reduction factor of changing X_e at a single detector location on the basement centerline. As expected, the exposure rate in the basement increases as the exterior wall mass thickness increases from zero to about 21 psf. From 21 psf up, the exposure rate decreases. The two points on the curve shown in Figure 4-4 are the exterior wall mass thicknesses used in this work and little difference in the results

is predicted. Figure 4-5 compares EM 1, EM 3 and the experimental results for Houses 1 and 12. Over most of the range, the error bars on the data encompass both calculations. The experimental results are noted to drop significantly as the floor panel is approached. This trend is noted in nearly all of the experiments performed and is clearly the trend for the detector locations below grade. It was thought that the trend might be due to localized floor barrier effects since the detector rack for this data was located immediately beneath the intersection of two floor joists. Experiments performed in this region however indicated that the exposure rate did not change significantly when the detectors were moved from beneath the joists. It is believed that any effects the joists have on the ground contribution in the basement could not account for the rather significant drop in the data noted in Figures 4-5 and 4-6, and in general in most of the tests performed.

Table 4-1. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 1

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	3	0.003510	0.001190	0.000774	0.005209	0.010683
		0.0001067	0.0000651	0.0000795	0.0009426	0.0010150
2	3	0.004033	0.001345	0.000885	0.005804	0.012066
		0.0001145	0.0000618	0.0000839	0.0009564	0.0010447
3	3	0.005427	0.001927	0.001305	0.009582	0.018241
		0.0001447	0.0000867	0.0001142	0.0012978	0.0014406
4	3	0.005080	0.001727	0.001249	0.008498	0.016554
		0.0001234	0.0000739	0.0000795	0.0010149	0.0011596
5	3	0.003438	0.001077	0.000711	0.004026	0.009251
		0.0001218	0.0000732	0.0000947	0.0010876	0.0011410
6	3	0.005573	0.001954	0.001240	0.009009	0.017776
		0.0002129	0.0001632	0.0002168	0.0023583	0.0024520
7	3	0.005327	0.001804	0.001229	0.008227	0.016587
		0.0001398	0.0001100	0.0001179	0.0014413	0.0015530
1	6	0.004352	0.001507	0.000926	0.006469	0.013254
		0.0001241	0.0000858	0.0001021	0.0012021	0.0012894
2	6	0.005952	0.001857	0.001259	0.007111	0.016179
		0.0001659	0.0000838	0.0000970	0.0012363	0.0013591
3	6	0.006431	0.002326	0.001506	0.011095	0.021358
		0.0002423	0.0001332	0.0001363	0.0018197	0.0019711
4	6	0.006599	0.002278	0.001389	0.009195	0.019461
		0.0001056	0.0001092	0.0000976	0.0012615	0.0014218
5	6	0.004271	0.001395	0.000913	0.005628	0.012207
		0.0001151	0.0000843	0.0000861	0.0010896	0.0011711
6	6	0.006110	0.002205	0.003546	0.012406	0.024268
		0.0001814	0.0002175	0.0020512	0.0038953	0.0044810
7	6	0.006255	0.002341	0.001546	0.012114	0.022255
		0.0001497	0.0001356	0.0001430	0.0017344	0.0018946
6	2	0.005050	0.001783	0.001156	0.008165	0.016154
		0.0004171	0.0002012	0.0002046	0.0028340	0.0029261
6	3	0.005470	0.001954	0.001240	0.009330	0.017993
		0.0001873	0.0001632	0.0002168	0.0023239	0.0024185
6	4	0.005971	0.002035	0.001182	0.007536	0.016723
		0.0001907	0.0002125	0.0001945	0.0024732	0.0025553
6	5	0.006139	0.002191	0.001414	0.010224	0.019968
		0.0002196	0.0002070	0.0002062	0.0025608	0.0026665
6	6	0.006110	0.002208	0.001499	0.010966	0.020783
		0.0001814	0.0001862	0.0001531	0.0020485	0.0021774
6	7	0.005514	0.002203	0.001155	0.008886	0.017757
		0.0002602	0.0003302	0.0002485	0.0033760	0.0034593
6	8	0.004172	0.001667	0.000974	0.008421	0.015234
		0.0002270	0.0002044	0.0002163	0.0026204	0.0026926
0	3	0.177750	0.046176	0.028310	0.077396	0.329633
		0.0039103	0.0008160	0.0006855	0.0151838	0.0190017
0	4	0.174680	0.046370	0.030184	0.090901	0.342135
		0.0028261	0.0006772	0.0011506	0.0152528	0.0191135
0	5	0.185512	0.055231	0.034038	0.152131	0.426912
		0.0049473	0.0016592	0.0010194	0.0208254	0.0255603
0	6	0.193382	0.056426	0.030989	0.112231	0.393027
		0.0017675	0.0010968	0.0008558	0.0126178	0.0180682

Table 4-2. EXPFRIMENTAL REDUCTION FACTORS FOR HOUSE 2

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	4	0.004518	0.001530	0.001128	0.007551	0.014726
		0.0001130	0.0000500	0.0000733	0.0008368	0.0009740
2	4	0.005147	0.001718	0.001204	0.007888	0.015957
		0.0001708	0.0000513	0.0000656	0.0009438	0.0010928
3	4	0.006797	0.002251	0.001534	0.009935	0.020517
		0.0001765	0.0000730	0.0001185	0.0012867	0.0014657
4	4	0.006646	0.002179	0.001590	0.010183	0.020599
		0.0001250	0.0000570	0.0000640	0.0008534	0.0010940
5	4	0.004271	0.001373	0.001023	0.006241	0.012908
		0.0001530	0.0000502	0.0000709	0.0009211	0.0010268
6	4	0.007420	0.002416	0.001746	0.010729	0.022311
		0.0002101	0.0001110	0.0001997	0.0018859	0.0020434
7	4	0.007316	0.002298	0.001526	0.008734	0.019875
		0.0002048	0.0000731	0.0001069	0.0013128	0.0014822
1	7	0.005902	0.001887	0.001393	0.008479	0.017661
		0.0001366	0.0000600	0.0000726	0.0009375	0.0011109
2	7	0.009314	0.002487	0.001738	0.006224	0.019762
		0.0002061	0.0000543	0.0000711	0.0010722	0.0012689
3	7	0.008642	0.002761	0.001949	0.011493	0.024845
		0.0001980	0.0000729	0.0001513	0.0014207	0.0016535
4	7	0.009318	0.002721	0.001936	0.010135	0.024109
		0.0001439	0.0002380	0.0001440	0.0020555	0.0022211
5	7	0.006078	0.001785	0.001308	0.006438	0.015609
		0.0001353	0.0000551	0.0000735	0.0009149	0.0010581
6	7	0.008165	0.002604	0.001981	0.011960	0.024711
		0.0002107	0.0001057	0.0001349	0.0016264	0.0018331
7	7	0.008775	0.002738	0.001913	0.010875	0.024301
		0.0001675	0.0000898	0.0001099	0.0013365	0.0015667
6	3	0.007059	0.002322	0.001763	0.011292	0.022436
		0.0002342	0.0001055	0.0001360	0.0016774	0.0018512
6	4	0.007420	0.002416	0.001746	0.010729	0.022311
		0.0002101	0.0001110	0.0001997	0.0018859	0.0020434
6	5	0.007953	0.002510	0.001834	0.010591	0.022888
		0.0002071	0.0001057	0.0001606	0.0017231	0.0018971
6	6	0.008121	0.002442	0.001685	0.009091	0.021340
		0.0001989	0.0004081	0.0002307	0.0033167	0.0034261
6	7	0.008165	0.002604	0.001981	0.011960	0.024711
		0.0002107	0.0001057	0.0001349	0.0016264	0.0018331
6	8	0.007277	0.002600	0.001715	0.012634	0.024226
		0.0002454	0.0003170	0.0003584	0.0040845	0.0041939
6	9	0.005471	0.001914	0.001351	0.009692	0.018428
		0.0002174	0.0002817	0.0005047	0.0043089	0.0043937
0	2	0.134469	0.046241	0.028980	0.203224	0.412914
		0.0029082	0.0005717	0.0010479	0.0146998	0.0201244
0	3	0.147918	0.045476	0.031135	0.177161	0.401693
		0.0026419	0.0003579	0.0003244	0.0087408	0.0159071
0	4	0.156083	0.054976	0.034599	0.203653	0.449311
		0.0030699	0.0006037	0.0002953	0.0092911	0.0175549
0	5	0.167318	0.056697	0.035757	0.213044	0.472815
		0.0022058	0.0006285	0.0003857	0.0085720	0.0177093

Table 4-3. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 3

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	4	0.003739	0.001452	0.001174	0.009480	0.015845
		0.0001338	0.0000516	0.0000736	0.0008937	0.0010432
2	4	0.004361	0.001628	0.001260	0.009853	0.017103
		0.0001974	0.0000530	0.0000689	0.0010340	0.0011928
3	4	0.005870	0.002164	0.001678	0.012826	0.022537
		0.0001768	0.0000838	0.0001063	0.0013052	0.0015121
4	4	0.005727	0.002098	0.001657	0.012516	0.021999
		0.0001707	0.0000517	0.0000753	0.0009919	0.0012367
5	4	0.003786	0.001322	0.001062	0.007583	0.013753
		0.0001527	0.0000541	0.0000678	0.0009223	0.0010393
6	4	0.006655	0.002293	0.001831	0.012500	0.023278
		0.0003326	0.0001029	0.0001640	0.0020114	0.0021824
7	4	0.005937	0.002209	0.001647	0.012795	0.022588
		0.0001966	0.0000753	0.0001133	0.0013304	0.0015372
1	7	0.005009	0.001796	0.001423	0.010477	0.018705
		0.0001603	0.0000576	0.0000764	0.0009978	0.0011823
2	7	0.007456	0.002308	0.001753	0.009680	0.021198
		0.0001489	0.0000549	0.0000876	0.0010009	0.0012[illegible]74
3	7	0.007247	0.002721	0.002043	0.016062	0.028074
		0.0002190	0.0000820	0.0001106	0.0014076	0.0016958
4	7	0.007609	0.002679	0.002059	0.014701	0.027049
		0.0001505	0.0000588	0.0000824	0.0010083	0.0013482
5	7	0.004952	0.001754	0.001272	0.009226	0.017204
		0.0001173	0.0000582	0.0000785	0.0009172	0.0010841
6	7	0.006878	0.002629	0.002064	0.016243	0.027815
		0.0002658	0.0001021	0.0002064	0.0019498	0.0021767
7	7	0.007377	0.002703	0.002064	0.015727	0.027870
		0.0002286	0.0001023	0.0001195	0.0015661	0.0018290
6	3	0.006158	0.002247	0.001769	0.013232	0.023407
		0.0002641	0.0000994	0.0001465	0.0017553	0.0019384
6	4	0.006655	0.002293	0.001831	0.012500	0.023278
		0.0003326	0.0001029	0.0001640	0.0020114	0.0021824
6	5	0.006702	0.002400	0.001953	0.014619	0.025673
		0.0002683	0.0001641	0.0001644	0.0021683	0.0023494
6	6	0.006890	0.002538	0.001973	0.014851	0.026251
		0.0002233	0.0001108	0.0001876	0.0018788	0.0020858
6	7	0.006878	0.002629	0.001951	0.015783	0.027242
		0.0002658	0.0001021	0.0001878	0.0019075	0.0021293
6	8	0.006459	0.002363	0.001789	0.013578	0.024188
		0.0002414	0.0001247	0.0001529	0.0018745	0.0020555
6	9	0.005045	0.001950	0.001505	0.012231	0.020731
		0.0002513	0.0001238	0.0001495	0.0018713	0.0020134
0	2	0.130495	0.049452	0.027414	0.204691	0.412052
		0.0022992	0.0007886	0.0007874	0.0123924	0.0183950
0	3	0.140562	0.048135	0.030125	0.205787	0.424609
		0.0015838	0.0008203	0.0009996	0.0122900	0.0185616
0	4	0.153111	0.056203	0.031451	0.300793	0.541558
		0.0034902	0.0015002	0.0025258	0.0185384	0.0258927
0	5	0.167777	0.055711	0.035679	0.223107	0.482274
		0.0024557	0.0011461	0.0011308	0.0158578	0.0224553

Table 4-4. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 4

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	5	0.004869	0.001772	0.001222	0.009281	0.017143
		0.0001291	0.0000486	0.0000654	0.0008316	0.0010117
2	5	0.005724	0.002045	0.001426	0.010489	0.019684
		0.0001199	0.0000676	0.0000800	0.0009812	0.0011811
3	5	0.007729	0.002626	0.001822	0.012298	0.024474
		0.0002135	0.0000776	0.0000924	0.0012843	0.0015292
4	5	0.007511	0.002538	0.001751	0.011726	0.023527
		0.0001584	0.0000487	0.0000673	0.0009120	0.0012020
5	5	0.004529	0.001590	0.001132	0.008094	0.015345
		0.0001645	0.0000497	0.0000690	0.0009392	0.0010788
6	5	0.008293	0.002807	0.001996	0.013430	0.026526
		0.0003098	0.0000966	0.0001333	0.0017971	0.0020227
7	5	0.008135	0.002694	0.001823	0.011724	0.024376
		0.0002111	0.0000711	0.0000950	0.0012662	0.0015118
1	8	0.007514	0.002280	0.001614	0.008572	0.019979
		0.0001416	0.0000489	0.0000682	0.0008754	0.0011011
2	8	0.011374	0.003016	0.002005	0.006263	0.022658
		0.0001679	0.0000494	0.0000720	0.0009602	0.0012235
3	8	0.010674	0.003141	0.002270	0.012392	0.028476
		0.0002173	0.0001643	0.0000963	0.0015150	0.0017972
4	8	0.011336	0.003323	0.002261	0.010858	0.027779
		0.0001794	0.0000536	0.0000698	0.0009956	0.0013579
5	8	0.007754	0.002189	0.001513	0.006391	0.017846
		0.0001276	0.0000487	0.0000667	0.0008349	0.0010269
6	8	0.009852	0.003217	0.002179	0.013523	0.028771
		0.0005357	0.0001031	0.0001336	0.0024015	0.0026366
7	8	0.010092	0.003270	0.002272	0.014057	0.029691
		0.0003684	0.0000693	0.0001013	0.0017078	0.0019983
6	4	0.007846	0.002686	0.001996	0.013679	0.026207
		0.0002393	0.0000982	0.0001317	0.0016305	0.0018612
6	5	0.008293	0.002807	0.001996	0.013430	0.026526
		0.0003098	0.0000966	0.0001333	0.0017971	0.0020227
6	6	0.009059	0.002367	0.002078	0.012176	0.025680
		0.0003714	0.0003108	0.0001345	0.0022764	0.0024753
6	7	0.009741	0.003141	0.002057	0.012411	0.027351
		0.0003104	0.0000988	0.0001279	0.0017808	0.0020197
6	8	0.009852	0.003217	0.002179	0.013523	0.028771
		0.0005357	0.0001031	0.0001336	0.0024015	0.0026366
6	9	0.010197	0.002944	0.002016	0.009148	0.024305
		0.0002775	0.0000977	0.0001368	0.0017383	0.0019358
6	10	0.016960	0.003505	0.001995	0.003115	0.025575*
		0.0008129	0.0000987	0.0001316	0.0057003	0.0057603
0	1	0.037958	0.040007	0.028369	0.405341	0.511675
		0.0008465	0.0007600	0.0007193	0.0091933	0.0190060
0	2	0.091182	0.045028	0.031011	0.309981	0.477203
		0.0010118	0.0010925	0.0008377	0.0114494	0.0193162
0	3	0.116421	0.054675	0.036375	0.318055	0.525526
		0.0148963	0.0009429	0.0007296	0.0176970	0.0250712
0	4	0.136356	0.054964	0.036344	0.304861	0.532525
		0.0022790	0.0008533	0.0008304	0.0128012	0.0216389

*Three area far field gave negative result, see page 136.

Table 4-5. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 5

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	5	0.006748	0.001876	0.001914	0.005938	0.016476
		0.0001640	0.0000605	0.0001752	0.0012439	0.0013761
2	5	0.008224	0.002197	0.002186	0.005231	0.017839
		0.0001318	0.0000647	0.0002109	0.0012387	0.0013909
3	5	0.010945	0.002907	0.002907	0.006174	0.022933
		0.0003222	0.0000801	0.0003578	0.0020457	0.0022305
4	5	0.010573	0.002772	0.002772	0.005667	0.021785
		0.0001663	0.0000718	0.0002563	0.0014339	0.0016287
5	5	0.006556	0.001733	0.001787	0.004582	0.014658
		0.0001443	0.0000612	0.0001625	0.0011888	0.0012999
6	5	0.012006	0.003109	0.003030	0.005120	0.023264
		0.0003044	0.0001202	0.0005349	0.0025064	0.0026914
7	5	0.011396	0.003016	0.003192	0.007306	0.024909
		0.0001876	0.0000872	0.0002731	0.0016850	0.0018995
1	8	0.010548	0.002571	0.002493	0.002419	0.018031
		0.0001735	0.0000611	0.0002264	0.0013103	0.0014640
2	8	0.017265	0.003588	0.003427	0.042498	0.066779*
		0.0002106	0.0000717	0.0002729	0.0108064	0.0108122
3	8	0.014863	0.003760	0.003614	0.005536	0.027773
		0.0001865	0.0001336	0.0004577	0.0023970	0.0026111
4	8	0.015405	0.003774	0.003669	0.003386	0.026234
		0.0001681	0.0000804	0.0003214	0.0015749	0.0018278
5	8	0.010954	0.002510	0.002447	0.000386	0.016297
		0.0001595	0.0000727	0.0002298	0.0014134	0.0015362
6	8	0.014562	0.003573	0.003641	0.003907	0.025684
		0.0003208	0.0001404	0.0005099	0.0027966	0.0029826
7	8	0.015761	0.003637	0.003552	0.006462	0.029612
		0.0009208	0.0001668	0.0004565	0.0049090	0.0051091
6	4	0.011044	0.002970	0.002987	0.006729	0.023731
		0.0002758	0.0001349	0.0005466	0.0026310	0.0028119
6	5	0.012006	0.003109	0.003030	0.005120	0.023264
		0.0003044	0.0001202	0.0005349	0.0025064	0.0026914
6	6	0.012594	0.003326	0.003257	0.006449	0.025625
		0.0004725	0.0001290	0.0006172	0.0031490	0.0033506
6	7	0.013767	0.003480	0.003399	0.004133	0.024779
		0.0002204	0.0001241	0.0006272	0.0023755	0.0025971
6	8	0.014562	0.003573	0.003641	0.003907	0.025684
		0.0003208	0.0001404	0.0005099	0.0027966	0.0029826
6	9	0.014759	0.003480	0.003316	0.000977	0.022532
		0.0004532	0.0001241	0.0005567	0.0030135	0.0031851
6	10	0.037822	0.006647	0.004213	0.018103	0.066785*
		0.0006846	0.0001026	0.0006796	0.0266623	0.0266799
0	1	0.048347	0.043732	0.028045	0.345259	0.465382
		0.0003855	0.0016106	0.0007192	0.0106314	0.0185390
0	2	0.102555	0.046890	0.031365	0.325536	0.506345
		0.0011747	0.0006582	0.0010143	0.0105581	0.0195836
0	3	0.128259	0.056417	0.035929	0.352773	0.573378
		0.0016786	0.0006396	0.0008500	0.0108518	0.0216081
0	4	0.146290	0.058782	0.036301	0.270725	0.512098
		0.0027218	0.0013291	0.0006886	0.0129088	0.0212519

*ibid.

Table 4-6. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 6

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	6	0.008146	0.002336	0.001441	0.006051	0.017974
		0.0001573	0.0000513	0.0000738	0.0009500	0.0011290
2	6	0.010805	0.002839	0.001649	0.003960	0.019253
		0.0001827	0.0000622	0.0000676	0.0010175	0.0012109
3	6	0.013322	0.003656	0.002189	0.007306	0.026473
		0.0002278	0.0000849	0.0001082	0.0014298	0.0016885
4	6	0.013367	0.003537	0.002232	0.006269	0.025405
		0.0001515	0.0000532	0.0000895	0.0010030	0.0013106
5	6	0.007940	0.002152	0.001324	0.004277	0.015694
		0.0001393	0.0000507	0.0000678	0.0008763	0.0010262
6	6	0.014132	0.003874	0.002359	0.007982	0.028347
		0.0003148	0.0001001	0.0001289	0.0018015	0.0020530
7	6	0.014090	0.003717	0.002199	0.005686	0.025693
		0.0003911	0.0000725	0.0001079	0.0018129	0.0020370
1	9	0.022598	0.003999	0.002314	0.000568	0.029478 *
		0.0003122	0.0000546	0.0000720	0.0033125	0.0033284
2	9	0.024679	0.005105	0.002929	0.005198	0.037911*
		0.0003491	0.0000576	0.0000772	0.0033407	0.0033603
3	9	0.019823	0.004937	0.002939	0.004882	0.032581
		0.0004091	0.0000734	0.0000987	0.0018053	0.0021345
4	9	0.020686	0.005053	0.002999	0.003613	0.032351
		0.0002426	0.0000586	0.0000775	0.0012138	0.0016250
5	9	0.026188	0.004105	0.002228	0.000569	0.033089*
		0.0002684	0.0000576	0.0000764	0.0033125	0.0033248
6	9	0.018919	0.004702	0.002839	0.004642	0.031102
		0.0004486	0.0000996	0.0001380	0.0021933	0.0024610
7	9	0.019554	0.004847	0.002738	0.002982	0.030122
		0.0002507	0.0000773	0.0001727	0.0016409	0.0019349
6	5	0.013075	0.003638	0.002259	0.008382	0.027355
		0.0002073	0.0001144	0.0001340	0.0016610	0.0019022
6	6	0.014132	0.003874	0.002359	0.007982	0.028347
		0.0003148	0.0001001	0.0001289	0.0018015	0.0020530
6	7	0.015888	0.004207	0.002579	0.007305	0.029979
		0.0002869	0.0001264	0.0001421	0.0019136	0.0021735
6	8	0.017089	0.004515	0.002659	0.006851	0.031115
		0.0005737	0.0001066	0.0001402	0.0025481	0.0028053
6	9	0.018919	0.004702	0.002839	0.004642	0.031102
		0.0004486	0.0000996	0.0001380	0.0021933	0.0024610
6	10	0.045728	0.007793	0.004658	0.013237	0.071416*
		0.0014665	0.0001811	0.0001635	0.0078259	0.0079639
6	11	0.056605	0.012839	0.006937	0.000885	0.077266*
		0.0014384	0.0003876	0.0001690	0.0117204	0.0118159
0	0	0.021220	0.008020	0.006129	0.048157	0.083526
		0.0003248	0.0003166	0.0005417	0.0048658	0.0056125
0	1	0.033549	0.031218	0.027354	0.338896	0.431017
		0.0010787	0.0009102	0.0003765	0.0064462	0.0154516
0	2	0.082528	0.054583	0.033198	0.446038	0.616346
		0.0014131	0.0006677	0.0008151	0.0102510	0.0225181
0	3	0.116696	0.055421	0.034268	0.292104	0.498489
		0.0020899	0.0015234	0.0005566	0.0103618	0.0193722

*ibid.

Table 4-7. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 7

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	6	0.005413	0.001932	0.001309	0.009455	0.018109
		0.0001339	0.0000787	0.0000739	0.0010150	0.0011849
2	6	0.006768	0.002233	0.001785	0.010268	0.021054
		0.0001167	0.0000658	0.0002326	0.0012311	0.0014329
3	6	0.009122	0.002916	0.001989	0.011888	0.025915
		0.0002629	0.0000842	0.0001135	0.0015359	0.0017757
4	6	0.008711	0.002794	0.001900	0.011443	0.024848
		0.0001417	0.0000636	0.0000860	0.0010304	0.0013197
5	6	0.005117	0.001827	0.001180	0.008799	0.016923
		0.0001441	0.0000684	0.0000924	0.0010906	0.0012345
6	6	0.009661	0.003077	0.002220	0.013437	0.028395
		0.0001637	0.0001611	0.0001626	0.0019988	0.0022183
7	6	0.008949	0.003031	0.001959	0.013450	0.027390
		0.0003470	0.0000857	0.0001590	0.0019442	0.0021727
1	9	0.014341	0.002910	0.001890	0.009219	0.028360*
		0.0002676	0.0000637	0.0000742	0.0033060	0.0033183
2	9	0.016256	0.003697	0.002412	0.008455	0.029524*
		0.0001827	0.0000615	0.0000749	0.0032370	0.0032545
3	9	0.013983	0.003760	0.002392	0.007100	0.027236
		0.0003409	0.0000837	0.0002592	0.0020857	0.0023064
4	9	0.013654	0.003801	0.002641	0.011020	0.031115
		0.0002347	0.0000602	0.0000790	0.0012055	0.0015921
5	9	0.016279	0.002921	0.001869	0.008455	0.029524*
		0.0003235	0.0000628	0.0000725	0.0032370	0.0032545
6	9	0.012798	0.003633	0.002515	0.011298	0.030244
		0.0004260	0.0001189	0.0001406	0.0021973	0.0024503
7	9	0.013326	0.003783	0.002576	0.011169	0.030855
		0.0003036	0.0000848	0.0001153	0.0016499	0.0019582
6	5	0.008980	0.002916	0.002113	0.013005	0.027014
		0.0003193	0.0001179	0.0001900	0.0021549	0.0023583
6	6	0.009661	0.003077	0.002220	0.013437	0.028395
		0.0001637	0.0001611	0.0001626	0.0019988	0.0022183
6	7	0.010421	0.003355	0.002281	0.013834	0.029891
		0.0002850	0.0001190	0.0001371	0.0018508	0.0021160
6	8	0.011323	0.003471	0.002428	0.013238	0.030460
		0.0003082	0.0001180	0.0001534	0.0019824	0.0022442
6	9	0.012798	0.003633	0.002515	0.011298	0.030244
		0.0004260	0.0001189	0.0001406	0.0021973	0.0024503
6	10	0.020984	0.005368	0.003031	0.005247	0.034631
		0.0004057	0.0001233	0.0001354	0.0021263	0.0024451
6	11	0.024260	0.006016	0.003336	0.003347	0.036959
		0.0008922	0.0001433	0.0001921	0.0037578	0.0040507
0	0	0.016812	0.007174	0.005723	0.051202	0.080911
		0.0003920	0.0003151	0.0005142	0.0048637	0.0055720
0	1	0.024539	0.028363	0.028363	0.363083	0.444348
		0.0002838	0.0003191	0.0009065	0.0053816	0.0154040
0	2	0.069560	0.052919	0.034826	0.384882	0.542187
		0.0013315	0.0017014	0.0004313	0.0076600	0.0192923
0	3	0.097834	0.055964	0.035065	0.391673	0.580535
		0.0025728	0.0008081	0.0007873	0.0130427	0.0230624

*ibid.

Table 4-8. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 8 AND 9.

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	6	0.011039	0.003080	0.001628	0.003942	0.019690
		0.0001884	0.0002011	0.0001198	0.0017772	0.0019120
2	6	0.013213	0.003302	0.001802	0.001665	0.019982
		0.0001960	0.0001929	0.0000903	0.0014474	0.0016119
3	6	0.016767	0.004872	0.002464	0.005216	0.029319
		0.0003530	0.0003986	0.0001322	0.0022540	0.0025069
4	6	0.015923	0.004238	0.002497	0.006694	0.029352
		0.0002203	0.0001699	0.0001123	0.0016894	0.0019618
5	6	0.010604	0.002939	0.001517	0.002640	0.017700
		0.0002296	0.0002096	0.0000787	0.0013599	0.0015104
6	6	0.017866	0.005186	0.002633	0.005339	0.031023
		0.0005991	0.0004902	0.0001385	0.0027259	0.0030099
7	6	0.016837	0.004696	0.002475	0.005077	0.029085
		0.0003874	0.0003174	0.0001184	0.0021100	0.0023676
1	9	0.027889	0.005412	0.003308	0.015352	0.051961*
		0.0003663	0.0001675	0.0000810	0.0061229	0.0061458
2	9	0.027286	0.006450	0.003923	0.005896	0.043554
		0.0005528	0.0001629	0.0000824	0.0020006	0.0025166
3	9	0.025407	0.006207	0.003732	0.006706	0.042052
		0.0006586	0.0002723	0.0001054	0.0024611	0.0029040
4	9	0.026103	0.006340	0.004058	0.007964	0.044465
		0.0004722	0.0001471	0.0001298	0.0022777	0.0027433
5	9	0.033494	0.005338	0.003412	0.015352	0.057596*
		0.0005450	0.0002002	0.0000904	0.0061229	0.006151[illegible]
6	9	0.025171	0.005764	0.003702	0.006500	0.041136
		0.0008915	0.0002944	0.0001363	0.0032631	0.0036503
7	9	0.024984	0.006449	0.003712	0.007370	0.042514
		0.0007535	0.0002536	0.0001238	0.0028474	0.0032639
6	5	0.016122	0.004232	0.002464	0.005777	0.028595
		0.0005296	0.0003268	0.0001349	0.0025416	0.0027792
6	6	0.017866	0.004580	0.002633	0.004954	0.030033
		0.0005991	0.0002992	0.0001385	0.0027022	0.0029524
6	7	0.019376	0.005023	0.002892	0.006010	0.033301
		0.0004040	0.0002442	0.0001683	0.0026262	0.0028832
6	8	0.021356	0.005542	0.003233	0.007160	0.037292
		0.0008016	0.0005530	0.0001535	0.0032739	0.0036264
6	9	0.025171	0.005764	0.003702	0.006500	0.041136
		0.0008915	0.0002944	0.0001363	0.0032631	0.0036503
6	10	0.108384	0.022192	0.012481	0.015452	0.158510*
		0.0192584	0.0008960	0.0005970	0.0323238	0.0376414
6	11	0.168148	0.038096	0.019896	0.015452	0.241592*
		0.0066460	0.0010507	0.0021289	0.0323238	0.0330852
0	0	0.035647	0.008791	0.006937	0.016656	0.068030
		0.0007928	0.0002854	0.0004353	0.0051785	0.0057075
0	1	0.060814	0.034510	0.028866	0.318304	0.442494
		0.0010545	0.0006897	0.0014384	0.0116569	0.0185777
0	2	0.116241	0.054792	0.036291	0.348213	0.555536
		0.0029722	0.0015170	0.0012293	0.0187304	0.0262207
0	3	0.144367	0.055971	0.036525	0.282274	0.519137
		0.0032447	0.0017283	0.0012229	0.0195314	0.0260666

*ibid.

Table 4-9. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 10

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	6	0.008488	0.002393	0.001532	0.006179	0.018592
		0.0001487	0.0000647	0.0000779	0.0010118	0.0011913
2	6	0.011224	0.002861	0.001690	0.003302	0.019077
		0.0001419	0.0000728	0.0000795	0.0010428	0.0012253
3	6	0.014090	0.003709	0.002331	0.006635	0.026765
		0.0002744	0.0000963	0.0001175	0.0016312	0.0018739
4	6	0.013767	0.003597	0.002129	0.005129	0.024622
		0.0001711	0.0000711	0.0000872	0.0011363	0.0014035
5	6	0.008344	0.002197	0.001351	0.003687	0.015579
		0.0001294	0.0000649	0.0000779	0.0009741	0.0011094
6	6	0.015041	0.004049	0.002365	0.006769	0.028224
		0.0003840	0.0001500	0.0001654	0.0023425	0.0025537
7	6	0.014671	0.003771	0.002223	0.004633	0.025299
		0.0002031	0.0000965	0.0001174	0.0014773	0.0017085
1	9	0.023541	0.004025	0.002335	0.004827	0.034728*
		0.0002375	0.0000755	0.0000802	0.0036562	0.0036656
2	9	0.018371	0.005109	0.003053	0.008790	0.035323
		0.0042966	0.0000796	0.0000970	0.0038129	0.0058587
3	9	0.020985	0.004994	0.003044	0.003698	0.032720
		0.0002874	0.0001628	0.0001185	0.0018385	0.0021511
4	9	0.022189	0.005128	0.003134	0.001855	0.032306
		0.0003149	0.0000789	0.0000860	0.0014885	0.0018505
5	9	0.026986	0.004067	0.002343	0.004827	0.033396*
		0.0004267	0.0001338	0.0000864	0.0036562	0.0036844
6	9	0.020510	0.004928	0.002804	0.001366	0.029608
		0.0003406	0.0001121	0.0001659	0.0020865	0.0023302
7	9	0.020627	0.005112	0.002947	0.003798	0.032485
		0.0002113	0.0001156	0.0001175	0.0015764	0.0019144
6	5	0.014183	0.003836	0.002272	0.006802	0.027093
		0.0004168	0.0001832	0.0001691	0.0025327	0.0027242
6	6	0.015041	0.004049	0.002365	0.006769	0.028224
		0.0003840	0.0001500	0.0001654	0.0023425	0.0025537
6	7	0.016603	0.004304	0.002618	0.006407	0.029932
		0.0005063	0.0001383	0.0001678	0.0026082	0.0028368
6	8	0.018246	0.004662	0.002804	0.005911	0.031622
		0.0003653	0.0001465	0.0001659	0.0022931	0.0025477
6	9	0.020510	0.004928	0.002804	0.001366	0.029608
		0.0003406	0.0001121	0.0001659	0.0020865	0.0023302
6	10	0.048087	0.008980	0.004826	0.015452	0.077345*
		0.0006050	0.0006537	0.0001788	0.0323238	0.0323379
6	11	0.059297	0.012973	0.006841	0.015452	0.094563*
		0.0006799	0.0002826	0.0001663	0.0323238	0.0323326
0	0	0.022789	0.008494	0.006643	0.050135	0.088061
		0.0007659	0.0003681	0.0008805	0.0067960	0.0074716
0	1	0.036314	0.028914	0.024784	0.302649	0.392661
		0.0007470	0.0010233	0.0007617	0.0103341	0.0164581
0	2	0.078220	0.045615	0.028728	0.293324	0.445886
		0.0020283	0.0012796	0.0006375	0.0111649	0.0183911
0	3	0.104053	0.046951	0.030657	0.290883	0.472545
		0.0018938	0.0007465	0.0007451	0.0111176	0.0190464

*ibid.

Table 4-10. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 11

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	3	0.004074	0.000975	0.001121	0.004061	0.010231
		0.0001746	0.0000677	0.0000911	0.0011469	0.0012119
2	3	0.004754	0.001099	0.001182	0.003014	0.010049
		0.0001603	0.0000659	0.0000985	0.0011349	0.0011974
3	3	0.005995	0.001605	0.001412	0.004107	0.013120
		0.0002708	0.0000878	0.0002230	0.0018640	0.0019458
4	3	0.005879	0.001539	0.001464	0.004549	0.013431
		0.0001812	0.0000654	0.0001274	0.0012663	0.0013588
5	3	0.003670	0.000796	0.000957	0.002933	0.008356
		0.0001908	0.0000734	0.0000917	0.0012131	0.0012630
6	3	0.006999	0.001838	0.001652	0.004515	0.015004
		0.0003580	0.0001109	0.0002684	0.0023829	0.0024753
7	3	0.006502	0.001604	0.001522	0.005590	0.015218
		0.0002399	0.0001096	0.0001287	0.0016714	0.0017672
1	6	0.005061	0.001245	0.001199	0.002971	0.010475
		0.0001827	0.0000694	0.0001247	0.0012942	0.0013579
2	6	0.006778	0.001594	0.001478	0.002848	0.012699
		0.0001894	0.0000652	0.0001127	0.0012473	0.0013334
3	6	0.007630	0.002109	0.001867	0.008473	0.020079
		0.0002701	0.0001061	0.0001422	0.0017871	0.0019291
4	6	0.007535	0.002045	0.001751	0.007128	0.018460
		0.0002820	0.0000702	0.0001159	0.0015373	0.0016790
5	6	0.004757	0.000973	0.001149	0.001703	0.008582
		0.0001593	0.0000691	0.0001003	0.0011588	0.0012084
6	6	0.007589	0.002057	0.001893	0.009152	0.020691
		0.0003143	0.0001905	0.0002015	0.0025893	0.0027073
7	6	0.008046	0.002154	0.001918	0.006495	0.018613
		0.0002784	0.0000962	0.0001850	0.0018883	0.0020126
6	2	0.006451	0.001762	0.001442	0.005531	0.015186
		0.0003405	0.0001113	0.0001888	0.0021636	0.0022555
6	3	0.006959	0.001838	0.001652	0.004754	0.015203
		0.0004050	0.0001109	0.0002604	0.0025231	0.0026186
6	4	0.007257	0.001882	0.001743	0.004138	0.015019
		0.0003660	0.0001221	0.0003231	0.0025791	0.0026724
6	5	0.007012	0.002023	0.001797	0.009239	0.020071
		0.0006361	0.0000994	0.0001875	0.0029704	0.0031139
6	6	0.007589	0.002057	0.001893	0.009152	0.020691
		0.0003143	0.0001905	0.0002015	0.0025893	0.0027073
6	7	0.006984	0.001936	0.001731	0.006899	0.017549
		0.0003394	0.0001019	0.0001904	0.0021060	0.0022182
6	8	0.005322	0.001501	0.001487	0.008177	0.016487
		0.0003690	0.0001402	0.0001588	0.0022368	0.0023387
0	3	0.153394	0.041641	0.026269	0.087822	0.309126
		0.0030633	0.0006127	0.0010288	0.0152174	0.0185128
0	4	0.149368	0.040399	0.026665	0.100126	0.316558
		0.0029743	0.0005952	0.0006587	0.0127528	0.0166579
0	5	0.158277	0.048052	0.030203	0.145273	0.381805
		0.0044357	0.0006026	0.0006582	0.0159867	0.0207149
0	6	0.167206	0.049740	0.032684	0.162522	0.412152
		0.0042432	0.0013931	0.0008630	0.0177402	0.0226664

Table 4-11. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 12

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	3	0.003878	0.001184	0.000811	0.014397	0.01027[illegible]
		0.0003901	0.0009597	[illegible]	[illegible]17151	0.0017936
2	3	0.004663	0.001289	0.000864	0.003518	0.010334
		0.0003961	0.0006699	0.0000921	0.0017229	0.0018030
3	3	0.006841	0.001828	0.001141	0.00358[illegible]	0.013393
		0.0007509	[illegible]846	0.0001662	0.0031268	0.0032499
4	3	0.006501	0.001771	[illegible]	[illegible]	0.013235
		0.0004122	0.0000651	[illegible]	[illegible]	0.0018987
5	3	0.003739	0.001033	[illegible]	[illegible]	0.008026
		0.0003994	[illegible]	[illegible]	0.0019700	0.0020331
6	3	0.006954	0.002098	[illegible]	[illegible]	0.017212
		0.0008965	0.0001387	[illegible]	[illegible]	0.0043127
7	3	0.006607	[illegible]	[illegible]	[illegible]	0.016581
		0.0006522	[illegible]	[illegible]	[illegible]	0.0029073
1	6	0.004705	[illegible]	[illegible]	[illegible]	0.011391
		0.0003905	[illegible]	[illegible]	[illegible]	0.0020220
2	6	0.006545	[illegible]	0.001151	[illegible]	0.013790
		0.0006734	[illegible]	[illegible]	[illegible]	0.0027595
3	6	0.007377	[illegible]	[illegible]	[illegible]	0.019969
		0.0006507	[illegible]	[illegible]	[illegible]	0.0029639
4	6	0.007839	[illegible]	[illegible]	[illegible]	0.017926
		0.0006853	[illegible]	0.0001410	[illegible]	0.0029737
5	6	0.004350	[illegible]	[illegible]	[illegible]	0.010536
		0.0004692	[illegible]	[illegible]	0.0021414	0.0022210
6	6	0.007391	0.002340	[illegible]	[illegible]	[illegible]
		0.0008375	0.0001625	[illegible]	[illegible]	[illegible]
7	6	0.007755	[illegible]	[illegible]	[illegible]	[illegible]
		0.0006507	[illegible]	[illegible]	[illegible]28911	[illegible]
6	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		0.0011664	0.0001448	[illegible]	[illegible]	[illegible]
6	3	0.006954	[illegible]	[illegible]	[illegible]	[illegible]
		0.0008965	[illegible]	[illegible]	[illegible]	[illegible]
6	4	0.007813	0.002168	[illegible]	[illegible]	0.016838
		0.0011717	[illegible]	[illegible]	[illegible]	[illegible]
6	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		0.0008284	0.0001861	[illegible]	[illegible]	[illegible]3425
6	6	0.007391	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]8375	[illegible]	[illegible]	[illegible]	[illegible]
6	7	0.006594	0.002151	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	8	[illegible]4723	[illegible]1637	[illegible]	[illegible]	[illegible]15624
		[illegible]8583	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]64232	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4	[illegible]82524	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5	0.096195	[illegible]	[illegible]	[illegible]	[illegible]
		0.0045582	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6	0.102902	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 4-12. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 13

GD. PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	5	0.006546	0.001382	0.000963	0.000534	0.009424
		0.0001648	0.0001211	0.0000858	0.0012698	0.0013247
2	5	0.008239	0.001680	0.001114	0.005972	0.017005*
		0.0001496	0.0001127	0.0000969	0.0047170	0.0047217
3	5	0.010886	0.002253	0.001555	0.000834	0.015528
		0.0002454	0.0002294	0.0001280	0.0019701	0.0020648
4	5	0.010868	0.002217	0.001402	0.005948	0.020435*
		0.0002627	0.0001497	0.0001433	0.0067312	0.0067395
5	5	0.006417	0.001381	0.000889	0.004150	0.012837*
		0.0001828	0.0000687	0.0000894	0.0038904	0.0038963
6	5	0.011598	0.002652	0.001707	0.000982	0.016938*
		0.0006671	0.0001292	0.0001888	0.0031297	0.0032547
7	5	0.011969	0.002514	0.001555	0.005756	0.021794*
		0.0003729	0.0000960	0.0001504	0.0063442	0.0063577
1	8	0.010184	0.001918	0.001300	0.007618	0.021020*
		0.0001750	0.0000997	0.0001151	0.0051390	0.0051442
2	8	0.016755	0.002845	0.001643	0.003200	0.024443*
		0.0003716	0.0000894	0.0001282	0.0054821	0.0054969
3	8	0.014398	0.003044	0.002103	0.013220	0.032765*
		0.0004703	0.0001061	0.0001632	0.0069025	0.0069213
4	8	0.015644	0.003131	0.002032	0.009876	0.030683*
		0.0002285	0.0000718	0.0000977	0.0042161	0.0042240
5	8	0.010856	0.001610	0.001300	0.012321	0.026087*
		0.0002319	0.0000766	0.0001241	0.0052105	0.0052177
6	8	0.014062	0.002986	0.001970	0.010330	0.029348*
		0.0003489	0.0001619	0.0001561	0.0073162	0.0073279
7	8	0.015123	0.003098	0.001927	0.007399	0.027547*
		0.0003011	0.0000992	0.0001629	0.0068273	0.0068365
6	4	0.011393	0.002542	0.001500	0.003767	0.019202*
		0.0004384	0.0001201	0.0001583	0.0068717	0.0068885
6	5	0.011598	0.002652	0.001707	0.000982	0.016938
		0.0006671	0.0001292	0.0001888	0.0031297	0.0032547
6	6	0.012843	0.002776	0.001757	0.007490	0.024866*
		0.0003929	0.0001664	0.0001528	0.0072729	0.0072870
6	7	0.014125	0.002926	0.001964	0.011076	0.030091*
		0.0003524	0.0001187	0.0001832	0.0077446	0.0077557
6	8	0.014062	0.002986	0.001970	0.010330	0.029348*
		0.0003489	0.0001619	0.0001561	0.0073162	0.0073279
6	9	0.015407	0.002815	0.001982	0.013282	0.033486*
		0.0005174	0.0002848	0.0001841	0.0101161	0.0101350
6	10	0.036846	0.006377	0.002672	0.013282	0.059177*
		0.0010766	0.0001807	0.0001533	0.0101161	0.0101400
0	1	0.039508	0.019946	0.013489	0.151484	0.224427
		0.0006372	0.0005841	0.0008453	0.0085480	0.0112878
0	2	0.064112	0.027778	0.019177	0.174485	0.285551
		0.0013467	0.0006291	0.0005945	0.0086331	0.0127557
0	3	0.080539	0.037426	0.022110	0.209194	0.349270
		0.0019814	0.0007300	0.0006562	0.0106152	0.0156736
0	4	0.095757	0.037961	0.022760	0.173479	0.329957
		0.0025047	0.0007239	0.0006132	0.0113957	0.0158541

*ibid.

Table 4-13. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 14

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	5	0.005386	0.001473	0.001003	0.003966	0.011827
		0.0003681	0.0000649	0.0000910	0.0016373	0.0017250
2	5	0.006599	0.001703	0.001199	0.003966	0.013467
		0.0003764	0.0000635	0.0000926	0.0016681	0.0017684
3	5	0.008837	0.002356	0.001625	0.005931	0.018749
		0.0006100	0.0000848	0.0001423	0.0026332	0.0027753
4	5	0.008692	0.002260	0.001523	0.004728	0.017204
		0.0003694	0.0000652	0.0000964	0.0016749	0.0018073
5	5	0.005056	0.001291	0.000959	0.003616	0.010922
		0.0003838	0.0000858	0.0000907	0.0016979	0.0017807
6	5	0.008806	0.002593	0.001809	0.009249	0.022458
		0.0008199	0.0001166	0.0001756	0.0034359	0.0036127
7	5	0.009161	0.002404	0.001599	0.005264	0.018428
		0.0005354	0.0001136	0.0001349	0.0024231	0.0025585
1	8	0.008197	0.001920	0.001362	0.002627	0.014106
		0.0003432	0.0000666	0.0000878	0.0015539	0.0016594
2	8	0.012305	0.002786	0.001718	0.000555	0.017364
		0.0004073	0.0000754	0.0000960	0.0017844	0.0019188
3	8	0.010844	0.003053	0.001973	0.008177	0.024048
		0.0005752	0.0001315	0.0001365	0.0025515	0.0027357
4	8	0.012133	0.002977	0.002040	0.004539	0.021689
		0.0003602	0.0000807	0.0001093	0.0017547	0.0019291
5	8	0.008957	0.001881	0.001231	0.006224	0.018293*
		0.0003858	0.0000660	0.0000917	0.0039425	0.0039629
6	8	0.011248	0.003006	0.002001	0.007391	0.023646
		0.0007911	0.0001818	0.0001762	0.0034161	0.0035982
7	8	0.011004	0.002976	0.001919	0.006924	0.022823
		0.0005243	0.0001067	0.0001139	0.0022314	0.0024136
6	4	0.008793	0.002503	0.001706	0.007643	0.020645
		0.0007722	0.0001174	0.0001890	0.0033992	0.0035564
6	5	0.008806	0.002593	0.001809	0.009249	0.022458
		0.0008199	0.0001166	0.0001756	0.0034359	0.0036127
6	6	0.009118	0.002793	0.001807	0.009532	0.023250
		0.0007220	0.0001260	0.0001909	0.0032859	0.0034552
6	7	0.010048	0.002849	0.002176	0.010668	0.025740
		0.0007719	0.0001179	0.0001882	0.0033938	0.0035859
6	8	0.011248	0.002870	0.002001	0.006664	0.022782
		0.0007911	0.0001538	0.0001762	0.0033961	0.0035719
6	9	0.010825	0.002630	0.001832	0.003830	0.019117
		0.0008035	0.0001184	0.0002128	0.0036217	0.0037690
6	10	0.014885	0.002868	0.001761	0.006199	0.025713*
		0.0012625	0.0001214	0.0002006	0.0084004	0.0084980
0	1	0.040989	0.019416	0.013308	0.121255	0.194968
		0.0043958	0.0007814	0.0007231	0.0165868	0.0183164
0	2	0.062330	0.027375	0.018943	0.140249	0.248897
		0.0082368	0.0004718	0.0005913	0.0196797	0.0228201
0	3	0.081170	0.036653	0.023651	0.242163	0.383636
		0.0040476	0.0005641	0.0012827	0.0190918	0.0231814
0	4	0.091304	0.036872	0.023252	0.197020	0.348448
		0.0032052	0.0007474	0.0009270	0.0154030	0.0194018

*ibid.

Table 4-14. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 19

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	6	0.008416	0.001930	0.001191	0.002186	0.013724
		0.0009111	0.0000705	0.0000929	0.0027144	0.0028999
2	6	0.010977	0.002264	0.001780	0.015961	0.030982*
		0.0001866	0.0000828	0.0001180	0.0050512	0.0050567
3	6	0.013538	0.003195	0.001753	0.000979	0.019465*
		0.0004211	0.0001533	0.0001414	0.0067205	0.0067369
4	6	0.013950	0.003007	0.001943	0.009243	0.028143*
		0.0002388	0.0000895	0.0001149	0.0050134	0.0050212
5	6	0.008007	0.001836	0.001219	0.000266	0.011328
		0.0001865	0.0000652	0.0001072	0.0012232	0.0012967
6	6	0.015113	0.003326	0.002220	0.001034	0.021694
		0.0006497	0.0002079	0.0002115	0.0033920	0.0035369
7	6	0.014775	0.003146	0.001987	0.008370	0.028278*
		0.0003927	0.0001052	0.0001359	0.0059224	0.0059379
1	9	0.024232	0.003263	0.002081	0.009664	0.039213*
		0.0003539	0.0000791	0.0001196	0.0050715	0.0050858
2	9	0.019929	0.004077	0.002514	0.007453	0.033973
		0.0048159	0.0002056	0.0001254	0.0060066	0.0077808
3	9	0.019436	0.003987	0.002620	0.013498	0.039541*
		0.0006069	0.0001038	0.0001897	0.0078489	0.0078753
4	9	0.021806	0.004132	0.002423	0.005691	0.034052*
		0.0002304	0.0000943	0.0002766	0.0110554	0.0110617
5	9	0.028248	0.003388	0.001930	0.003056	0.036622*
		0.0002691	0.0000689	0.0001025	0.0043573	0.0043673
6	9	0.019743	0.003743	0.002386	0.010581	0.036453*
		0.0005021	0.0008291	0.0001929	0.0220454	0.0220675
7	9	0.019978	0.004080	0.002513	0.009040	0.035611*
		0.0002531	0.0000953	0.0001355	0.0058026	0.0058104
6	5	0.014098	0.003077	0.001951	0.008401	0.027527*
		0.0003899	0.0001150	0.0002186	0.0090072	0.0090190
6	6	0.015113	0.003326	0.002220	0.001034	0.021694
		0.0006497	0.0002079	0.0002115	0.0033920	0.0035369
6	7	0.016275	0.003799	0.002221	0.001439	0.023734
		0.0007366	0.0003659	0.0002034	0.0036759	0.0038499
6	8	0.017445	0.003727	0.002495	0.013919	0.037586*
		0.0003855	0.0001279	0.0002825	0.0114854	0.0114961
6	9	0.019743	0.003743	0.002386	0.010718	0.036581*
		0.0005021	0.0008291	0.0001929	0.0220454	0.220675
6	10	0.051444	0.009059	0.004590	0.010718	0.075811*
		0.0004125	0.0004550	0.0002687	0.0220454	0.0220556
6	11	0.061660	0.014176	0.007196	0.010718	0.093750*
		0.0008377	0.0004978	0.0006328	0.0220454	0.0220760
0	0	0.021655	0.007443	0.005288	0.036512	0.070898
		0.0004516	0.0008629	0.0007432	0.0094336	0.0097863
0	1	0.033170	0.019678	0.015370	0.172593	0.240812
		0.0007197	0.0007952	0.0007309	0.0092825	0.0121959
0	2	0.059021	0.029058	0.018116	0.213083	0.319279
		0.0010078	0.0005116	0.0008856	0.0086829	0.0135827
0	3	0.074142	0.030651	0.019006	0.189181	0.312981
		0.0015237	0.0006315	0.0012474	0.0117044	0.0156245

*ibid.

Table 4-15. EXPERIMENTAL REDUCTION FACTORS FOR HOUSE 20

GD.PT.	HT.	AREA 1	AREA 2	AREA 3	FARFIELD	TOTAL
1	3	0.003637	0.001204	0.000821	0.005276	0.010938
		0.0001639	0.0000625	0.0000765	0.0010277	0.0011038
2	3	0.004094	0.001304	0.000893	0.005297	0.011588
		0.0001823	0.0000620	0.0000795	0.0010836	0.0011656
3	3	0.005821	0.001852	0.001295	0.007709	0.016678
		0.0002849	0.0000819	0.0001109	0.0015695	0.0016899
4	3	0.005559	0.001757	0.001231	0.007229	0.015776
		0.0002045	0.0000654	0.0000840	0.0011730	0.0013001
5	3	0.003262	0.001067	0.000762	0.004814	0.009904
		0.0002001	0.0000588	0.0000777	0.0011059	0.0011728
6	3	0.006507	0.002060	0.001391	0.008115	0.018072
		0.0004223	0.0001158	0.0001569	0.0022698	0.0023898
7	3	0.006288	0.001925	0.001319	0.007137	0.016669
		0.0002250	0.0000871	0.0001081	0.0014321	0.0015932
1	6	0.004167	0.001410	0.001064	0.007128	0.013769
		0.0001796	0.0000584	0.0000855	0.0010883	0.0011944
2	6	0.006217	0.001795	0.001238	0.005734	0.014984
		0.0001737	0.0000721	0.0000855	0.0011374	0.0012538
3	6	0.007202	0.002240	0.001547	0.008712	0.019701
		0.0002680	0.0000827	0.0001176	0.0015381	0.0016925
4	6	0.007558	0.002223	0.001525	0.007387	0.018694
		0.0001859	0.0000600	0.0000812	0.0010924	0.0012669
5	6	0.004055	0.001278	0.000909	0.005311	0.011553
		0.0001873	0.0000621	0.0000841	0.0011183	0.0011987
6	6	0.007372	0.002241	0.001347	0.007393	0.018352
		0.0005420	0.0001150	0.0003549	0.0031193	0.0032391
7	6	0.007749	0.002277	0.001629	0.008008	0.019663
		0.0004424	0.0000820	0.0001414	0.0021474	0.0022891
6	2	0.006246	0.001934	0.001295	0.007152	0.016627
		0.0003896	0.0001154	0.0001515	0.0021575	0.0022657
6	3	0.006507	0.002060	0.001391	0.008115	0.018072
		0.0004223	0.0001158	0.0001569	0.0022698	0.0023898
6	4	0.007025	0.002151	0.001483	0.007930	0.018589
		0.0003015	0.0001157	0.0001891	0.0020949	0.0022117
6	5	0.007304	0.002168	0.001511	0.007540	0.018522
		0.0002719	0.0001207	0.0001556	0.0019272	0.0020462
6	6	0.007372	0.002241	0.001665	0.008097	0.020174
		0.0005420	0.0001150	0.0002027	0.0027983	0.0029335
6	7	0.006324	0.002077	0.001583	0.009962	0.019947
		0.0002227	0.0001205	0.0001749	0.0019089	0.0020387
6	8	0.004837	0.001699	0.001294	0.009169	0.016999
		0.0003489	0.0001168	0.0001857	0.0022078	0.0023125
0	3	0.068083	0.020006	0.012911	0.060553	0.161554
		0.0024970	0.0005541	0.0007246	0.0119586	0.0133221
0	4	0.071137	0.023716	0.016038	0.101102	0.211992
		0.0020785	0.0007113	0.0003887	0.0083482	0.0110389
0	5	0.079577	0.029303	0.019567	0.140101	0.268548
		0.0006702	0.0019282	0.0008634	0.0128435	0.0156714
0	6	0.085419	0.032090	0.019493	0.121256	0.258257
		0.0065173	0.0007164	0.0008101	0.0216270	0.0241123

TABLE 4-16. THEORETICAL REDUCTION FACTORS FOR HOUSE 1
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	3	0.005961	0.009357	0.008660	0.011772	0.010683 0.0010150
2	3	0.007039	0.011281	0.011402	0.015459	0.012066 0.0010447
3	3	0.010726	0.015750	0.015538	0.019597	0.018241 0.0014406
4	3	0.009692	0.014514	0.014485	0.018513	0.016554 0.0011596
5	3	0.006648	0.010526	0.009366	0.012916	0.009251 0.0011410
6	3	0.011545	0.016809	0.016271	0.020465	0.017776 0.0024520
7	3	0.010630	0.015879	0.015406	0.019771	0.016587 0.0015530
1	6	0.009555	0.015559	0.013377	0.018955	0.013254 0.0012894
2	6	0.012460	0.019374	0.017762	0.023616	0.016179 0.0013591
3	6	0.017502	0.027950	0.022314	0.031317	0.021358 0.0019711
4	6	0.016246	0.025431	0.021194	0.028983	0.019461 0.0014218
5	6	0.010235	0.016844	0.013958	0.020097	0.012207 0.0011711
6	6	0.017879	0.029207	0.022532	0.032394	0.024268 0.0044810
7	6	0.017206	0.027445	0.022048	0.030854	0.022255 0.0018946
6	2	0.010216	0.014768	0.014977	0.018564	0.016154 0.0029261
6	3	0.011545	0.016809	0.016271	0.020465	0.017993 0.0024185
6	4	0.013550	0.020271	0.018404	0.023955	0.016723 0.0025553
6	5	0.015588	0.023854	0.020376	0.027302	0.019968 0.0026665
6	6	0.017879	0.029207	0.022532	0.032394	0.020783 0.0021774
6	7	0.020822	0.034255	0.025416	0.036856	0.017757 0.0034593
6	8	0.025414	0.041801	0.029877	0.043512	0.015234 0.0026926
0	3	0.450508	0.450229	0.450508	0.450229	0.329633 0.0190017
0	4	0.517175	0.513086	0.517175	0.513086	0.342135 0.0191135
0	5	0.549092	0.543345	0.549092	0.543345	0.426912 0.0255603
0	6	0.554029	0.547709	0.554029	0.547709	0.393027 0.0180682

TABLE 4-17. THEORETICAL REDUCTION FACTORS FOR HOUSE 2
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	4	0.009178	0.013484	0.011739	0.015778	0.014726 0.0009740
2	4	0.011741	0.016713	0.015907	0.020712	0.015957 0.0010928
3	4	0.017614	0.023800	0.022158	0.027434	0.020517 0.0014657
4	4	0.015815	0.021563	0.020354	0.025350	0.020599 0.0010940
5	4	0.009891	0.014696	0.012458	0.016962	0.012908 0.0010268
6	4	0.019187	0.026163	0.023658	0.029618	0.022311 0.0020434
7	4	0.016821	0.022996	0.021338	0.026682	0.019875 0.0014822
1	7	0.016877	0.024676	0.020548	0.027948	0.017661 0.0011109
2	7	0.024929	0.033655	0.030052	0.037757	0.019762 0.0012689
3	7	0.029791	0.043794	0.034369	0.047019	0.024845 0.0016535
4	7	0.028768	0.041601	0.033504	0.045010	0.024109 0.0022211
5	7	0.017548	0.025789	0.021111	0.028916	0.015609 0.0010581
6	7	0.030250	0.043870	0.034660	0.046940	0.024711 0.0018331
7	7	0.029206	0.042594	0.033820	0.045861	0.024301 0.0015667
6	3	0.015592	0.020683	0.020082	0.024254	0.022436 0.0018512
6	4	0.019187	0.026163	0.023658	0.029618	0.022311 0.0020434
6	5	0.021582	0.030162	0.026178	0.033661	0.022888 0.0018971
6	6	0.025000	0.037589	0.029518	0.040870	0.021340 0.0034261
6	7	0.030250	0.043870	0.034660	0.046940	0.024711 0.0018331
6	8	0.036021	0.051580	0.040403	0.054087	0.024226 0.0041939
6	9	0.046619	0.059647	0.050870	0.061292	0.018428 0.0043937
0	2	0.452083	0.453480	0.452083	0.453480	0.412914 0.0201244
0	3	0.505784	0.488594	0.505784	0.488594	0.401690 0.0159071
0	4	0.521138	0.513349	0.521138	0.513349	0.449311 0.0175549
0	5	0.524716	0.525915	0.524716	0.525915	0.472815 0.0177093

TABLE 4-18. THEORETICAL REDUCTION FACTORS FOR HOUSE 3
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	4	0.007489	0.011216	0.010050	0.013510	0.015845 0.0010432
2	4	0.009310	0.013765	0.013476	0.017763	0.017103 0.0011928
3	4	0.014024	0.019410	0.018567	0.023045	0.022537 0.0015121
4	4	0.012628	0.017713	0.017168	0.021500	0.021999 0.0012367
5	4	0.008178	0.012389	0.010743	0.014654	0.013753 0.0010393
6	4	0.015208	0.021064	0.019679	0.024519	0.023278 0.0021824
7	4	0.013584	0.019107	0.018101	0.022793	0.022588 0.0015372
1	7	0.013064	0.019698	0.016736	0.022970	0.018705 0.0011823
2	7	0.018519	0.025968	0.023642	0.030069	0.021198 0.0012274
3	7	0.023354	0.035134	0.027932	0.038358	0.028074 0.0016958
4	7	0.022260	0.032812	0.026995	0.036222	0.027049 0.0013482
5	7	0.013720	0.020883	0.017283	0.024011	0.017204 0.0010841
6	7	0.023721	0.035813	0.028131	0.038883	0.027815 0.0021767
7	7	0.022923	0.034307	0.027536	0.037575	0.027870 0.0018290
6	3	0.012774	0.017414	0.017265	0.020985	0.023407 0.0019384
6	4	0.015208	0.021064	0.019679	0.024519	0.023278 0.0021824
6	5	0.017377	0.024754	0.021973	0.028254	0.025673 0.0023494
6	6	0.020034	0.030067	0.024552	0.033348	0.026251 0.0020858
6	7	0.023721	0.035813	0.028131	0.038883	0.027242 0.0021293
6	8	0.027992	0.042037	0.032374	0.044544	0.024188 0.0020555
6	9	0.035324	0.049603	0.039574	0.051248	0.020731 0.0020134
0	2	0.447953	0.448830	0.447953	0.448830	0.412052 0.0183950
0	3	0.502906	0.484354	0.502906	0.484354	0.424609 0.0185616
0	4	0.518874	0.510544	0.518874	0.510544	0.541558 0.0258927
0	5	0.522618	0.523327	0.522618	0.523327	0.482274 0.0224553

TABLE 4-19. THEORETICAL REDUCTION FACTORS FOR HOUSE 4
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	5	0.009388	0.013361	0.011792	0.015520	0.017143 0.0010117
2	5	0.012354	0.016833	0.016293	0.020622	0.019684 0.0011811
3	5	0.017813	0.023849	0.022063	0.027250	0.024474 0.0015292
4	5	0.016326	0.021898	0.020585	0.025450	0.023527 0.0012020
5	5	0.010318	0.014824	0.012719	0.016951	0.015345 0.0010788
6	5	0.019040	0.025554	0.023211	0.028782	0.026526 0.0020227
7	5	0.017212	0.023483	0.021446	0.026942	0.024376 0.0015118
1	8	0.019564	0.026259	0.023067	0.029389	0.019979 0.0011011
2	8	0.027836	0.037009	0.032752	0.040947	0.022658 0.0012235
3	8	0.031096	0.043509	0.035408	0.046570	0.028476 0.0017972
4	8	0.030389	0.041967	0.034865	0.045205	0.027779 0.0013570
5	8	0.019959	0.027068	0.023339	0.030054	0.017846 0.0010269
6	8	0.030913	0.043615	0.035061	0.046542	0.028771 0.0026366
7	8	0.030623	0.042792	0.034980	0.045900	0.029691 0.0019983
6	4	0.016440	0.021676	0.020636	0.025007	0.026207 0.0018612
6	5	0.019040	0.025554	0.023211	0.028782	0.026526 0.0020227
6	6	0.021829	0.030969	0.026104	0.034254	0.025680 0.0024753
6	7	0.025888	0.036689	0.030112	0.039790	0.027351 0.0020197
6	8	0.030913	0.043615	0.035061	0.046542	0.028771 0.0026366
6	9	0.038034	0.050036	0.042146	0.052418	0.024305 0.0019358
6	10	0.055450	0.066450	0.059472	0.068024	0.025575 0.0057603
0	1	0.350067	0.325212	0.350067	0.325212	0.511675 0.0190060
0	2	0.436225	0.420014	0.436225	0.420014	0.477203 0.0193162
0	3	0.473351	0.452386	0.473351	0.452386	0.525526 0.0250712
0	4	0.488116	0.486465	0.488116	0.486465	0.532525 0.0216389

TABLE 4-20. THEORETICAL REDUCTION FACTORS FOR HOUSE 5
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	5	0.013164	0.018233	0.015568	0.020392	0.016476 0.0013761
2	5	0.018026	0.023397	0.021965	0.027185	0.017839 0.0013909
3	5	0.025526	0.033545	0.029776	0.036946	0.022933 0.0022305
4	5	0.023508	0.030740	0.027767	0.034293	0.021785 0.0016287
5	5	0.014399	0.020105	0.016801	0.022231	0.014658 0.0012999
6	5	0.027224	0.036060	0.031394	0.039288	0.023264 0.0026914
7	5	0.024405	0.032618	0.028639	0.036078	0.024909 0.0018995
1	8	0.030289	0.038938	0.033792	0.042069	0.018031 0.0014640
2	8	0.044097	0.057523	0.049013	0.061460	0.066779 0.0108122
3	8	0.046083	0.062358	0.050395	0.065418	0.027773 0.0026111
4	8	0.045790	0.061768	0.050266	0.065005	0.026234 0.0018278
5	8	0.030465	0.039283	0.033845	0.042269	0.016297 0.0015362
6	8	0.045471	0.061214	0.049619	0.064141	0.025684 0.0029826
7	8	0.045383	0.061356	0.049740	0.064464	0.029612 0.0051091
6	4	0.023237	0.030044	0.027433	0.033373	0.023731 0.0028119
6	5	0.027224	0.036060	0.031394	0.039288	0.023264 0.0026914
6	6	0.031000	0.043898	0.035275	0.047184	0.025625 0.0033506
6	7	0.037383	0.052267	0.041607	0.055368	0.024779 0.0025971
6	8	0.045471	0.061214	0.049619	0.064141	0.025684 0.0029826
6	9	0.057358	0.069622	0.061471	0.072005	0.022532 0.0031851
6	10	0.110369	0.112227	0.114391	0.113801	0.066785 0.0266799
0	1	0.359777	0.337434	0.359777	0.337434	0.465382 0.0185390
0	2	0.443103	0.428838	0.443103	0.428838	0.506345 0.0195836
0	3	0.478445	0.459333	0.478445	0.459333	0.573378 0.0216081
0	4	0.492432	0.491796	0.492432	0.491796	0.512098 0.0212519

TABLE 4-21. THEORETICAL REDUCTION FACTORS FOR HOUSE 6
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	6	0.018632	0.024669	0.020853	0.026668	0.017974 0.0011290
2	6	0.026566	0.032485	0.030239	0.036022	0.019253 0.0012109
3	6	0.035478	0.046584	0.039386	0.049717	0.026473 0.0016885
4	6	0.033405	0.042516	0.037338	0.045795	0.025405 0.0013106
5	6	0.019653	0.026446	0.021862	0.028407	0.015694 0.0010262
6	6	0.036650	0.049810	0.040447	0.052774	0.028347 0.0020530
7	6	0.034343	0.044961	0.038255	0.048162	0.025693 0.0020370
1	9	0.080032	0.092079	0.083334	0.095043	0.029478 0.0033284
2	9	0.079330	0.092779	0.084001	0.096521	0.037911 0.0033603
3	9	0.069503	0.082843	0.073509	0.085719	0.032581 0.0021345
4	9	0.071654	0.085268	0.075840	0.088313	0.032351 0.0016250
5	9	0.078639	0.090568	0.081810	0.093388	0.033089 0.0033248
6	9	0.066844	0.079299	0.070660	0.082038	0.031102 0.0024610
7	9	0.069322	0.082633	0.073393	0.085562	0.030122 0.0019349
6	5	0.031274	0.039943	0.035124	0.042998	0.027355 0.0019022
6	6	0.036650	0.049810	0.040447	0.052774	0.028347 0.0020530
6	7	0.043391	0.058594	0.047319	0.061647	0.029979 0.0021735
6	8	0.052613	0.069622	0.056521	0.072527	0.031115 0.0028053
6	9	0.066844	0.079299	0.070660	0.082038	0.031102 0.0024610
6	10	0.121540	0.122422	0.125076	0.124670	0.071416 0.0079659
6	11	0.141021	0.149254	0.144781	0.150743	0.077266 0.0118159
0	0	0.129676	0.150703	0.129676	0.150703	0.083526 0.0056125
0	1	0.355381	0.320441	0.355381	0.320441	0.431017 0.0154516
0	2	0.418088	0.400673	0.418088	0.400673	0.616346 0.0225181
0	3	0.450382	0.437702	0.450382	0.437702	0.498489 0.0193722

TABLE 4-22. THEORETICAL REDUCTION FACTORS FOR HOUSE 7
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	6	0.012003	0.016281	0.014223	0.018280	0.018109 0.0011849
2	6	0.016494	0.021005	0.020167	0.024542	0.021054 0.0014329
3	6	0.022578	0.029797	0.026486	0.032931	0.025915 0.0017757
4	6	0.021085	0.027279	0.025019	0.030558	0.024848 0.0013197
5	6	0.012810	0.017664	0.015019	0.019625	0.016923 0.0012345
6	6	0.023500	0.031782	0.027298	0.034746	0.028395 0.0022183
7	6	0.021968	0.029102	0.025879	0.032303	0.027390 0.0021727
1	9	0.043636	0.050903	0.046938	0.053868	0.028360 0.0033183
2	9	0.044813	0.053250	0.049484	0.056992	0.029524 0.0032545
3	9	0.042230	0.052751	0.046237	0.055627	0.027236 0.0023064
4	9	0.042735	0.052629	0.046920	0.055675	0.031115 0.0015921
5	9	0.043237	0.050806	0.046408	0.053626	0.029524 0.0032545
6	9	0.040990	0.051656	0.044806	0.054395	0.030244 0.0024503
7	9	0.042015	0.052400	0.046086	0.055328	0.030855 0.0019582
6	5	0.020272	0.026167	0.024123	0.029223	0.027014 0.0023583
6	6	0.023500	0.031782	0.027298	0.034746	0.028395 0.0022183
6	7	0.027691	0.037608	0.031619	0.040661	0.029891 0.0021160
6	8	0.033090	0.044500	0.036997	0.047406	0.030460 0.0022442
6	9	0.040990	0.051656	0.044806	0.054395	0.030244 0.0024503
6	10	0.058306	0.067102	0.062128	0.068951	0.034631 0.0024451
6	11	0.065966	0.078816	0.069727	0.080305	0.036959 0.0040507
0	0	0.107878	0.127510	0.107878	0.127510	0.080911 0.0055720
0	1	0.343150	0.304477	0.343150	0.304477	0.444348 0.0154040
0	2	0.409122	0.389260	0.409122	0.389260	0.542187 0.0192923
0	3	0.443285	0.428298	0.443285	0.428298	0.580535 0.0230624

TABLE 4-23. THEORETICAL REDUCTION FACTORS FOR HOUSE 8 AND 9
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	6	0.019318	0.025897	0.021538	0.027897	0.019690 0.0019120
2	6	0.026743	0.032733	0.030415	0.036271	0.019982 0.0016119
3	6	0.036081	0.048304	0.039990	0.051437	0.029319 0.0025069
4	6	0.033997	0.043706	0.037931	0.046985	0.029352 0.0019618
5	6	0.020261	0.027632	0.022470	0.029594	0.0177[illegible] 0.0015104
6	6	0.037279	0.052003	0.041077	0.054996	0.031023 0.0030099
7	6	0.035074	0.046627	0.038986	0.049828	0.029085 0.0023676
1	9	0.092181	0.106298	0.095483	0.109263	0.051961 0.0061458
2	9	0.089352	0.104654	0.094024	0.108396	0.043554 0.0025166
3	9	0.077598	0.091869	0.081604	0.094744	0.042052 0.0029040
4	9	0.080315	0.095347	0.084500	0.098392	0.044465 0.0027433
5	9	0.090362	0.104148	0.093534	0.106968	0.057596 0.0061511
6	9	0.074519	0.087372	0.078335	0.090111	0.041136 0.0036503
7	9	0.077683	0.092056	0.081754	0.094984	0.042514 0.0032639
6	5	0.031362	0.040379	0.035313	0.043434	0.028595 0.0027792
6	6	0.037279	0.052003	0.041077	0.054996	0.030033 0.0295240
6	7	0.045293	0.062456	0.049221	0.065509	0.033301 0.0028832
6	8	0.056638	0.076369	0.060545	0.079274	0.037292 0.0036264
6	9	0.074519	0.087372	0.078335	0.090111	0.041136 0.0036503
6	10	0.310902	0.278019	0.314724	0.280267	0.158510 0.0376414
6	11	0.397806	0.391054	0.401566	0.392543	0.241592 0.0330852
0	0	0.212956	0.237034	0.212956	0.237034	0.068030 0.0057075
0	1	0.395008	0.371217	0.395008	0.371217	0.442494 0.0185777
0	2	0.445377	0.432940	0.445377	0.432940	0.555536 0.0262207
0	3	0.471205	0.464064	0.471205	0.464064	0.519137 0.0260666

TABLE 4-24. THEORETICAL REDUCTION FACTORS FOR HOUSE 10
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	6	0.018632	0.024669	0.020853	0.026668	0.018592 0.0011913
2	6	0.026566	0.032485	0.030239	0.036022	0.019077 0.0012253
3	6	0.035478	0.046584	0.039386	0.049717	0.026765 0.0018739
4	6	0.033405	0.042516	0.037338	0.045795	0.024622 0.0014035
5	6	0.019653	0.026446	0.021862	0.028407	0.015579 0.0011094
6	6	0.036782	0.050023	0.040579	0.052987	0.028224 0.0025537
7	6	0.034343	0.044961	0.038255	0.048162	0.025299 0.0017085
1	9	0.080032	0.092079	0.083334	0.095043	0.034728 0.0036656
2	9	0.079330	0.092779	0.084001	0.096521	0.035323 0.0058587
3	9	0.069503	0.082843	0.073509	0.085719	0.032720 0.0021511
4	9	0.071654	0.085268	0.075840	0.088313	0.032306 0.0018505
5	9	0.078639	0.090568	0.081810	0.093388	0.033396 0.0036844
6	9	0.067527	0.080379	0.071343	0.083118	0.029608 0.0023302
7	9	0.069322	0.082633	0.073393	0.085562	0.032485 0.0019144
6	5	0.031365	0.040091	0.035215	0.043146	0.027093 0.0027242
6	6	0.036782	0.050023	0.040579	0.052987	0.028224 0.0025537
6	7	0.043598	0.058927	0.047526	0.061980	0.029932 0.0028368
6	8	0.052958	0.070175	0.056866	0.073080	0.031622 0.0025477
6	9	0.067527	0.080379	0.071343	0.083118	0.029608 0.0023302
6	10	0.122821	0.124867	0.126643	0.127115	0.077345 0.0323379
6	11	0.143269	0.152749	0.147029	0.154238	0.094563 0.0323326
0	0	0.115291	0.140231	0.115291	0.140231	0.088061 0.0074716
0	1	0.305999	0.289091	0.305999	0.289091	0.392661 0.0164581
0	2	0.360246	0.360729	0.360246	0.360729	0.445886 0.0183911
0	3	0.389533	0.395723	0.389533	0.395723	0.472545 0.0190464

TABLE 4-25. THEORETICAL REDUCTION FACTORS FOR HOUSE 11
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	3	0.005961	0.009357	0.008660	0.011772	0.010231 0.0012119
2	3	0.007039	0.011281	0.011402	0.015459	0.010049 0.0011974
3	3	0.010726	0.015750	0.015538	0.019597	0.013120 0.0019458
4	3	0.009692	0.014514	0.014485	0.018513	0.013431 0.0013588
5	3	0.006648	0.010526	0.009366	0.012916	0.008356 0.0012630
6	3	0.011668	0.017014	0.016394	0.020670	0.015004 0.0024753
7	3	0.010630	0.015879	0.015406	0.019771	0.015218 0.0017672
1	6	0.009555	0.015559	0.013377	0.018955	0.010475 0.0013579
2	6	0.012460	0.019374	0.017762	0.023616	0.012699 0.0013334
3	6	0.017502	0.027950	0.022314	0.031317	0.020079 0.0019291
4	6	0.016246	0.025431	0.021194	0.028983	0.018460 0.0016790
5	6	0.010235	0.016844	0.013958	0.020097	0.008582 0.0012084
6	6	0.018502	0.030220	0.023155	0.033422	0.020691 0.0027073
7	6	0.017206	0.027445	0.022048	0.030854	0.018613 0.0020126
6	2	0.010302	0.014913	0.015063	0.018709	0.015186 0.0022555
6	3	0.011668	0.017014	0.016394	0.020670	0.015203 0.0026186
6	4	0.013744	0.020594	0.018598	0.024278	0.015019 0.0026724
6	5	0.015905	0.024379	0.020693	0.027827	0.020071 0.0031139
6	6	0.018502	0.030220	0.023155	0.033422	0.020691 0.0027073
6	7	0.022240	0.036537	0.026834	0.039138	0.017549 0.0022182
6	8	0.027057	0.044421	0.031520	0.046132	0.016487 0.0023387
0	3	0.441848	0.455520	0.441848	0.455520	0.309126 0.0185128
0	4	0.469245	0.483026	0.469245	0.483026	0.316558 0.0166579
0	5	0.474808	0.488657	0.474808	0.488657	0.381805 0.0207149
0	6	0.477880	0.500488	0.477880	0.500488	0.412152 0.0226664

TABLE 4-26. THEORETICAL REDUCTION FACTORS FOR HOUSE 12
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	3	0.006035	0.009460	0.008842	0.011954	0.010270 0.0017936
2	3	0.007298	0.011640	0.012019	0.016195	0.010334 0.0018030
3	3	0.011141	0.016509	0.016214	0.020638	0.013390 0.0032499
4	3	0.010063	0.015160	0.015143	0.019461	0.013235 0.0018987
5	3	0.006760	0.010658	0.009593	0.013124	0.008026 0.0020331
6	3	0.011996	0.017618	0.016952	0.021504	0.017212 0.0043127
7	3	0.010987	0.016508	0.015989	0.020634	0.016581 0.0029070
1	6	0.009432	0.015194	0.013352	0.018682	0.011391 0.0020220
2	6	0.012654	0.019615	0.018186	0.024119	0.013790 0.0027595
3	6	0.017653	0.027986	0.022530	0.031384	0.019969 0.0029639
4	6	0.016384	0.025530	0.021415	0.029151	0.017926 0.0029737
5	6	0.010155	0.016512	0.013978	0.019849	0.010036 0.0022210
6	6	0.018043	0.029122	0.022746	0.032313	0.020067 0.0039055
7	6	0.017279	0.027366	0.022158	0.030790	0.020154 0.0030405
6	2	0.010678	0.015604	0.015711	0.019686	0.016158 0.0042655
6	3	0.011996	0.017618	0.016952	0.021504	0.017212 0.0043127
6	4	0.013935	0.020935	0.018957	0.024683	0.016838 0.0048097
6	5	0.015900	0.024358	0.020803	0.027895	0.018738 0.0043425
6	6	0.018043	0.029122	0.022746	0.032313	0.020067 0.0039055
6	7	0.020612	0.033488	0.025154	0.036025	0.018365 0.0040647
6	8	0.024623	0.039956	0.028933	0.041585	0.015624 0.0035615
0	3	0.237295	0.249658	0.237295	0.249658	0.142958 0.0195497
0	4	0.317912	0.313417	0.317912	0.313417	0.256627 0.0175274
0	5	0.336926	0.338753	0.336926	0.338753	0.290956 0.0194807
0	6	0.345017	0.350176	0.345017	0.350176	0.292691 0.0195948

TABLE 4-27. THEORETICAL REDUCTION FACTORS FOR HOUSE 13
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	5	0.013211	0.018278	0.015701	0.020498	0.009424 0.0013247
2	5	0.018240	0.023677	0.022494	0.027799	0.017005 0.0047217
3	5	0.025842	0.034145	0.030294	0.037772	0.015528 0.0020648
4	5	0.023799	0.031242	0.028289	0.035039	0.020435 0.0067395
5	5	0.014474	0.020167	0.016965	0.022350	0.012837 0.0038963
6	5	0.027569	0.036704	0.031915	0.040114	0.016935 0.0032547
7	5	0.024674	0.033110	0.029083	0.036758	0.027794 0.0063577
1	8	0.030152	0.038568	0.033732	0.041778	0.021020 0.0051442
2	8	0.044250	0.057707	0.049369	0.061880	0.024443 0.0054969
3	8	0.046140	0.062226	0.050483	0.065290	0.032765 0.0069213
4	8	0.045848	0.061739	0.050374	0.065020	0.030683 0.0042240
5	8	0.030357	0.038925	0.033814	0.041982	0.026087 0.0052177
6	8	0.045518	0.060982	0.049680	0.063879	0.029348 0.0073279
7	8	0.045382	0.061127	0.049752	0.064229	0.027547 0.0068365
6	4	0.023598	0.030721	0.028007	0.034282	0.019202 0.0068885
6	5	0.027569	0.036704	0.031915	0.040114	0.016938 0.0032547
6	6	0.031275	0.044396	0.035670	0.047795	0.024866 0.0072877
6	7	0.037579	0.052607	0.041876	0.055767	0.030091 0.0077557
6	8	0.045518	0.060982	0.049680	0.063879	0.029348 0.0073279
6	9	0.057059	0.068695	0.061098	0.071000	0.033486 0.0101350
6	10	0.109529	0.110222	0.113390	0.111706	0.059177 0.0101400
0	1	0.187187	0.194630	0.187187	0.194630	0.224427 0.0112878
0	2	0.282601	0.274063	0.282601	0.274063	0.285551 0.0127557
0	3	0.310916	0.307850	0.310916	0.307850	0.349270 0.0156736
0	4	0.323099	0.326521	0.323099	0.326521	0.329957 0.0158541

TABLE 4-28. THEORETICAL REDUCTION FACTORS FOR HOUSE 14
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	5	0.009435	0.013406	0.011925	0.015626	0.011827 0.0017250
2	5	0.012568	0.017113	0.016822	0.021235	0.013467 0.0017684
3	5	0.018129	0.024450	0.022581	0.028076	0.018749 0.0027753
4	5	0.016618	0.022399	0.021107	0.026197	0.017204 0.0018073
5	5	0.010392	0.014887	0.012883	0.017070	0.010922 0.0017807
6	5	0.019415	0.026197	0.023731	0.029608	0.022458 0.0036127
7	5	0.017481	0.023974	0.021890	0.027622	0.018428 0.0025585
1	8	0.019427	0.025888	0.023008	0.029098	0.014106 0.0016594
2	8	0.027989	0.037193	0.033108	0.041367	0.017364 0.0019188
3	8	0.031152	0.043377	0.035496	0.046442	0.024048 0.0027357
4	8	0.030447	0.041939	0.034973	0.045219	0.021689 0.0019291
5	8	0.019851	0.026710	0.023308	0.029767	0.018293 0.0039629
6	8	0.030960	0.043382	0.035122	0.046280	0.023646 0.0035982
7	8	0.030622	0.042564	0.034992	0.045666	0.022823 0.0024136
6	4	0.016801	0.022353	0.021210	0.025914	0.020645 0.0035564
6	5	0.019415	0.026197	0.023731	0.029608	0.022458 0.0036127
6	6	0.022104	0.031467	0.026499	0.034866	0.023250 0.0034552
6	7	0.026084	0.037028	0.030381	0.040189	0.025740 0.0035859
6	8	0.030960	0.043382	0.035122	0.046280	0.022782 0.0035719
6	9	0.037735	0.049109	0.047740	0.051413	0.019117 0.0037690
6	10	0.054610	0.064445	0.058471	0.065930	0.025713 0.0084980
0	1	0.177477	0.182408	0.177477	0.182408	0.194968 0.0183164
0	2	0.275724	0.265239	0.275724	0.265239	0.248897 0.0228201
0	3	0.305822	0.300904	0.305822	0.300904	0.383636 0.0231814
0	4	0.318783	0.321190	0.318783	0.321190	0.348448 0.0194018

TABLE 4-29. THEORETICAL REDUCTION FACTORS FOR HOUSE 15
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	4	0.009239	0.013557	0.011897	0.015922	
2	4	0.011978	0.017033	0.016481	0.021388	
3	4	0.017982	0.024482	0.022759	0.028371	
4	4	0.016148	0.022139	0.020948	0.026201	
5	4	0.009984	0.014792	0.012654	0.017124	
6	4	0.019587	0.026892	0.024261	0.030553	
7	4	0.017135	0.023559	0.021853	0.027457	
1	7	0.016747	0.024309	0.020507	0.027667	
2	7	0.025103	0.033870	0.030444	0.038223	
3	7	0.029894	0.043754	0.034520	0.046996	
4	7	0.028866	0.041630	0.033668	0.045095	
5	7	0.017455	0.025442	0.021106	0.028648	
6	7	0.030356	0.043712	0.034799	0.046762	
7	7	0.029243	0.042440	0.033882	0.045711	
6	3	0.016006	0.021442	0.020739	0.025273	
6	4	0.019587	0.026892	0.024261	0.030553	
6	5	0.021913	0.030744	0.026654	0.034376	
6	6	0.025256	0.038012	0.029868	0.041368	
6	7	0.030356	0.043712	0.034799	0.046762	
6	8	0.035757	0.050739	0.040073	0.053186	
6	9	0.045802	0.057720	0.049896	0.059279	
0	2	0.215975	0.228843	0.215975	0.228843	
0	3	0.303131	0.294517	0.303131	0.294517	
0	4	0.325363	0.326298	0.325363	0.326298	
0	5	0.334365	0.338692	0.334365	0.338692	

TABLE 4-30. THEORETICAL REDUCTION FACTORS FOR HOUSE 16
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	5	0.009435	0.013406	0.011925	0.015626	
2	5	0.012568	0.017113	0.016822	0.021235	
3	5	0.018129	0.024450	0.022581	0.028076	
4	5	0.016618	0.022399	0.021107	0.026197	
5	5	0.010392	0.014887	0.012883	0.017070	
6	5	0.019415	0.026197	0.023731	0.029608	
7	5	0.017481	0.023974	0.021890	0.027622	
1	8	0.019427	0.025888	0.023008	0.029098	
2	8	0.027989	0.037193	0.033108	0.041367	
3	8	0.031152	0.043377	0.035496	0.046442	
4	8	0.030447	0.041939	0.034973	0.045219	
5	8	0.019851	0.026710	0.023308	0.029767	
6	8	0.030960	0.043382	0.035122	0.046280	
7	8	0.030622	0.042564	0.034992	0.045666	
6	4	0.016801	0.022353	0.021210	0.025914	
6	5	0.019415	0.026197	0.023731	0.029608	
6	6	0.022104	0.031467	0.026499	0.034866	
6	7	0.026084	0.037028	0.030381	0.040189	
6	8	0.030960	0.043382	0.035122	0.046280	
6	9	0.037735	0.049109	0.047740	0.051413	
6	10	0.054610	0.064445	0.058471	0.065930	
0	1	0.177477	0.182408	0.177477	0.182408	
0	2	0.275724	0.265239	0.275724	0.265239	
0	3	0.305822	0.300904	0.305822	0.300904	
0	4	0.318783	0.321190	0.318783	0.321190	

TABLE 4-31. THEORETICAL REDUCTION FACTORS FOR HOUSE 17
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR B RRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	6	0.012038	0.016305	0.014333	0.018357	
2	6	0.016687	0.021257	0.020649	0.025104	
3	6	0.022839	0.030313	0.026917	0.033641	
4	6	0.021334	0.027702	0.025467	0.031193	
5	6	0.012868	0.017705	0.015152	0.019714	
6	6	0.023786	0.032337	0.027730	0.035458	
7	6	0.022192	0.029513	0.026253	0.032875	
1	9	0.043492	0.050533	0.046862	0.053570	
2	9	0.044945	0.053404	0.049804	0.057364	
3	9	0.042238	0.052525	0.046259	0.055390	
4	9	0.042750	0.052540	0.046967	0.055614	
5	9	0.043118	0.050441	0.046354	0.053325	
6	9	0.040995	0.051318	0.044813	0.054013	
7	9	0.041978	0.052107	0.046049	0.055019	
6	5	0.020578	0.026757	0.024609	0.030015	
6	6	0.023786	0.032337	0.027730	0.035458	
6	7	0.027905	0.038018	0.031926	0.041164	
6	8	0.033224	0.044752	0.037181	0.047702	
6	9	0.040995	0.051318	0.044813	0.054013	
6	10	0.057975	0.066084	0.061715	0.068246	
6	11	0.065114	0.076775	0.068711	0.078172	
0	0	0.103160	0.121545	0.103160	0.121545	
0	1	0.242902	0.225976	0.242902	0.225976	
0	2	0.282182	0.276533	0.282182	0.276533	
0	3	0.301886	0.298977	0.301886	0.298977	

TABLE 4-32. THEORETICAL REDUCTION FACTORS FOR HOUSE 18
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	6	0.018668	0.024693	0.020962	0.026745	
2	6	0.026759	0.032737	0.030721	0.036584	
3	6	0.035739	0.047100	0.039817	0.050428	
4	6	0.033653	0.042938	0.037786	0.046430	
5	6	0.019711	0.026487	0.021995	0.028496	
6	6	0.036936	0.050365	0.040879	0.053456	
7	6	0.034567	0.045372	0.038628	0.048734	
1	9	0.079889	0.091709	0.083258	0.094746	
2	9	0.079463	0.092932	0.084321	0.096893	
3	9	0.069511	0.082617	0.073531	0.085482	
4	9	0.071670	0.085179	0.075887	0.088253	
5	9	0.078520	0.090203	0.081756	0.093087	
6	9	0.066849	0.078961	0.070666	0.081657	
7	9	0.069285	0.082340	0.073356	0.085252	
6	5	0.031580	0.040532	0.035610	0.043790	
6	6	0.036936	0.050365	0.040879	0.053456	
6	7	0.043605	0.059004	0.047626	0.062150	
6	8	0.052748	0.069873	0.056705	0.072823	
6	9	0.066849	0.078961	0.070666	0.081657	
6	10	0.120923	0.121403	0.124664	0.123566	
6	11	0.140169	0.147212	0.014377	0.148610	
0	0	0.124959	0.144738	0.124959	0.144738	
0	1	0.255132	0.241940	0.255132	0.241940	
0	2	0.291148	0.287947	0.291148	0.287947	
0	3	0.308983	0.308381	0.308983	0.308381	

TABLE 4-33. THEORETICAL REDUCTION FACTORS FOR HOUSE 19
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	6	0.018668	0.024693	0.020962	0.026745	0.013724 0.0028999
2	6	0.026759	0.032737	0.030721	0.036584	0.030982 0.0050567
3	6	0.035739	0.047100	0.039817	0.050428	0.019465 0.0067369
4	6	0.033653	0.042938	0.037786	0.046430	0.028143 0.0050212
5	6	0.019711	0.026487	0.021995	0.028496	0.011328 0.0012967
6	6	0.037068	0.050578	0.041011	0.053699	0.021694 0.0035369
7	6	0.034567	0.045372	0.038628	0.048734	0.028278 0.0059379
1	9	0.079889	0.091709	0.083258	0.094746	0.039213 0.0050858
2	9	0.079463	0.092932	0.084321	0.096893	0.033973 0.0077808
3	9	0.069511	0.082617	0.073531	0.085482	0.039541 0.0078753
4	9	0.071670	0.085179	0.075887	0.088253	0.034052 0.0110617
5	9	0.078520	0.090203	0.081756	0.093087	0.036622 0.0043673
6	9	0.067533	0.080041	0.071350	0.082737	0.036453 0.0220675
7	9	0.069285	0.082340	0.073356	0.085252	0.035611 0.0058104
6	5	0.031671	0.040680	0.035701	0.043938	0.027527 0.0090190
6	6	0.037068	0.050578	0.041011	0.053699	0.021694 0.0035369
6	7	0.043812	0.059337	0.047833	0.062484	0.023734 0.0038499
6	8	0.053093	0.070426	0.057050	0.073376	0.037586 0.0114961
6	9	0.067533	0.080041	0.071350	0.082737	0.036581 0.0220675
6	10	0.122490	0.123848	0.126230	0.126011	0.075811 0.0220556
6	11	0.142417	0.150707	0.146014	0.152105	0.093750 0.0220760
0	0	0.111326	0.135053	0.111326	0.135053	0.070898 0.0097863
0	1	0.221755	0.220950	0.221755	0.220950	0.240812 0.0121959
0	2	0.253571	0.262878	0.253571	0.262878	0.319279 0.0135827
0	3	0.270704	0.283463	0.270704	0.283463	0.312981 0.0156245

TABLE 4-34. THEORETICAL REDUCTION FACTORS FOR HOUSE 20
EM1 = CO-60, USUAL FLOOR BARRIER FACTOR
EM2 = FISSION, USUAL FLOOR BARRIER FACTOR
EM3 = CO-60, MODIFIED FLOOR BARRIER FACTOR
EM4 = FISSION, MODIFIED FLOOR BARRIER FACTOR

GD.PT.	HT.	EM1	EM2	EM3	EM4	TOTAL EXP.
1	3	0.006035	0.009460	0.008842	0.011954	0.010938 0.0011038
2	3	0.007298	0.011640	0.012019	0.016195	0.011588 0.0011656
3	3	0.011141	0.016509	0.016214	0.020638	0.016678 0.0016899
4	3	0.010063	0.015160	0.015143	0.019461	0.015776 0.0013001
5	3	0.006760	0.010658	0.009593	0.013124	0.009904 0.0011728
6	3	0.012119	0.017823	0.017075	0.021709	0.018072 0.0023898
7	3	0.010987	0.016508	0.015989	0.020634	0.016669 0.0015532
1	6	0.009432	0.015194	0.013352	0.018682	0.013769 0.0011944
2	6	0.012654	0.019615	0.018186	0.024119	0.014984 0.0012538
3	6	0.017653	0.027986	0.022530	0.031384	0.019701 0.0016925
4	6	0.016384	0.025530	0.021415	0.029151	0.018694 0.0012669
5	6	0.010155	0.016512	0.013978	0.019849	0.011553 0.0011987
6	6	0.018666	0.030135	0.023369	0.033326	0.018352 0.0032391
7	6	0.017279	0.027366	0.022158	0.030790	0.019663 0.0022891
6	2	0.010764	0.015749	0.015797	0.019831	0.016627 0.0022657
6	3	0.012119	0.017823	0.017075	0.021709	0.018072 0.0023898
6	4	0.014129	0.021258	0.019151	0.025093	0.018589 0.0022117
6	5	0.016217	0.024884	0.021120	0.028420	0.018522 0.0020462
6	6	0.018666	0.030135	0.023369	0.033326	0.020174 0.0029335
6	7	0.022030	0.035770	0.026572	0.038307	0.019947 0.0020387
6	8	0.026266	0.042576	0.030576	0.044205	0.016999 0.0023125
0	3	0.209984	0.229422	0.209984	0.229422	0.161554 0.0133221
0	4	0.276559	0.284951	0.276559	0.284951	0.211992 0.0110389
0	5	0.293456	0.308234	0.293456	0.308234	0.268548 0.0156714
0	6	0.302068	0.320768	0.302068	0.320768	0.258257 0.0241123

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Fig. 2-1. The KSUNESF test structure and tubing field.

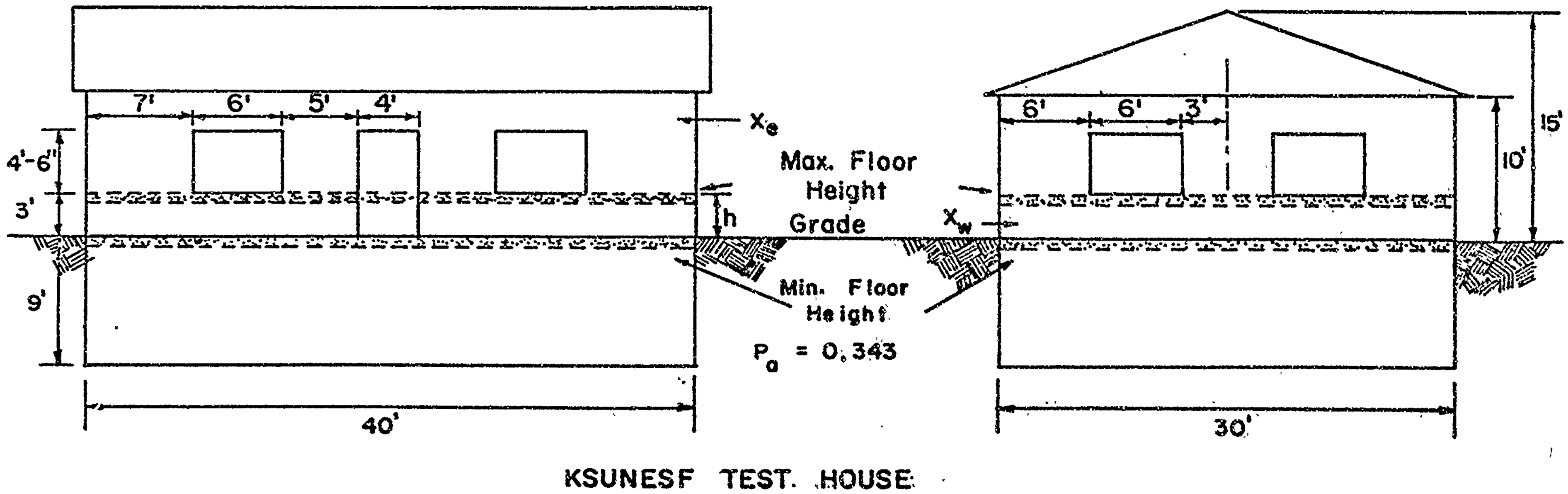


Fig. 2-2. Front and side views of the test structure showing nominal dimensions.

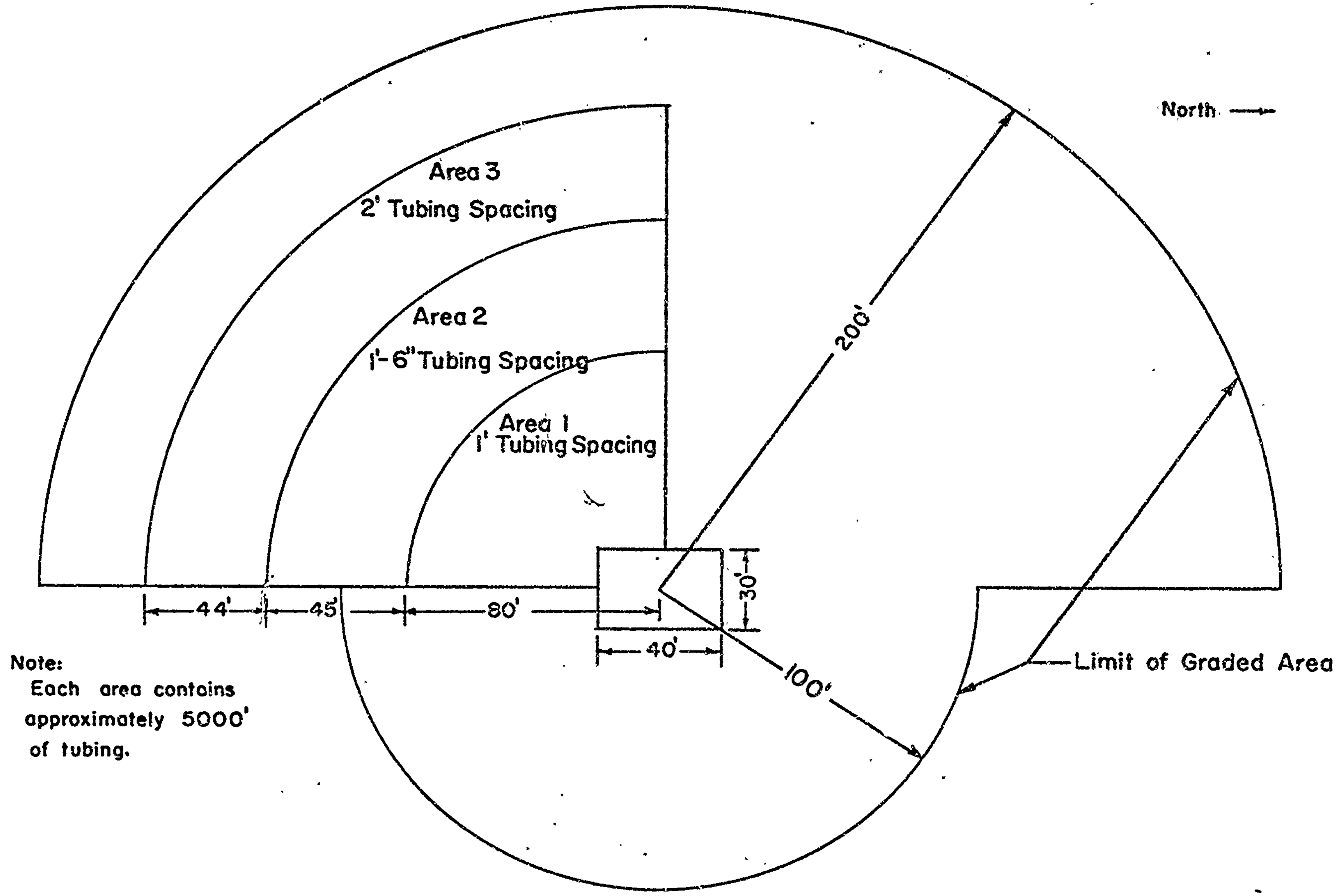


Fig. 2-3. Tubing areas for fallout simulation.

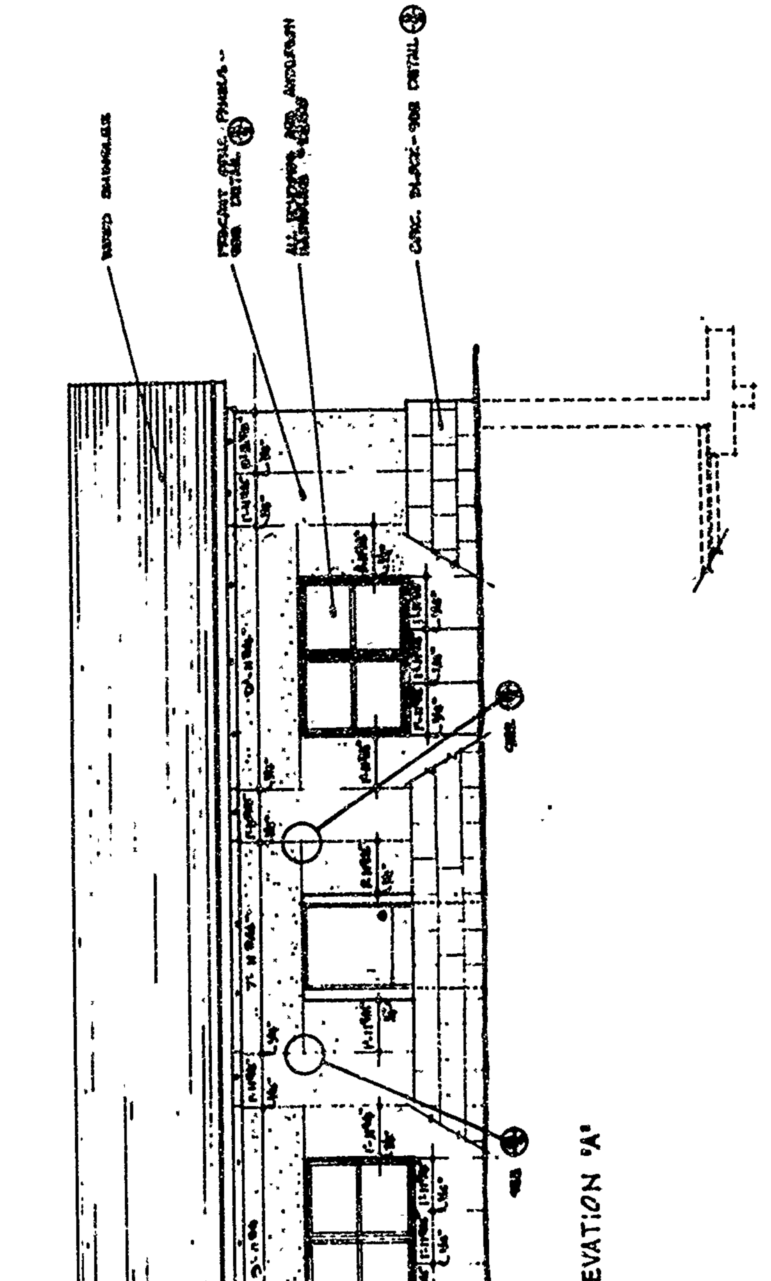


Fig. 2-4. Detailed Test Structure Drawings.

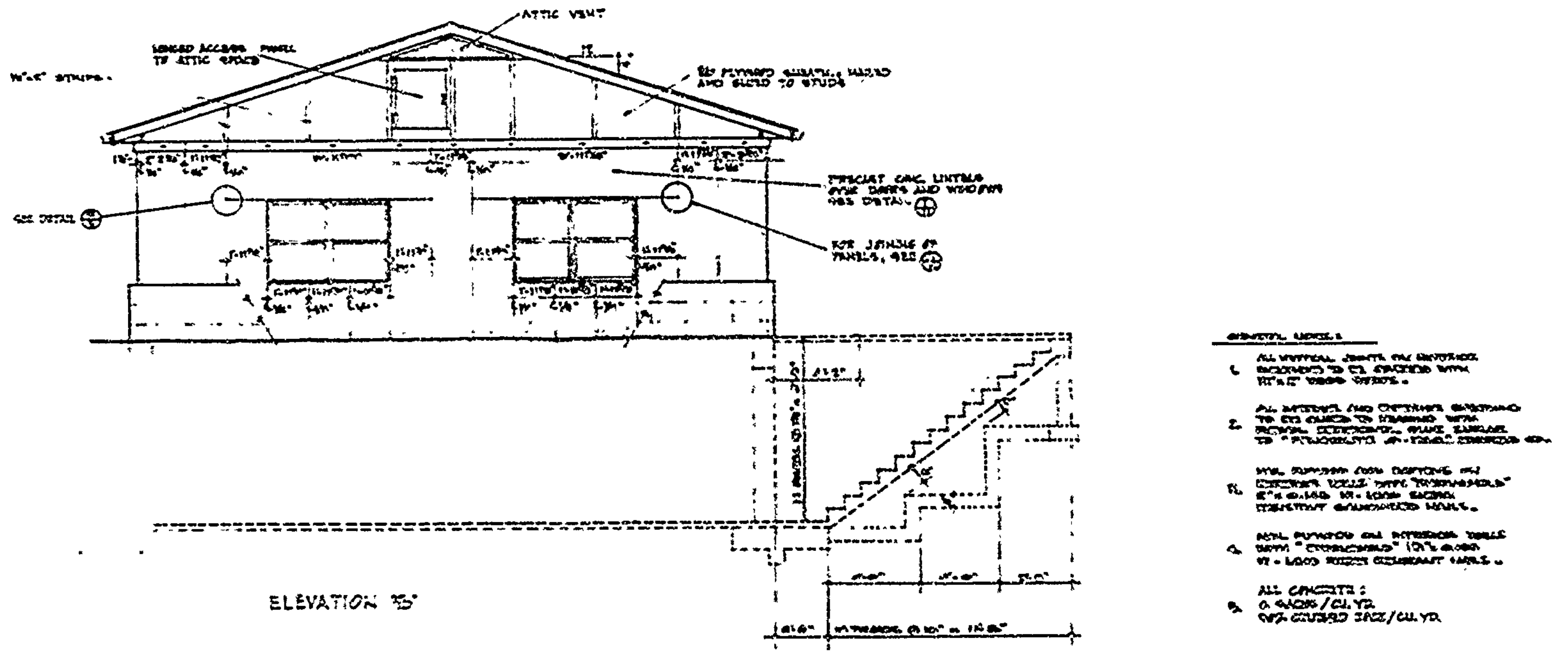
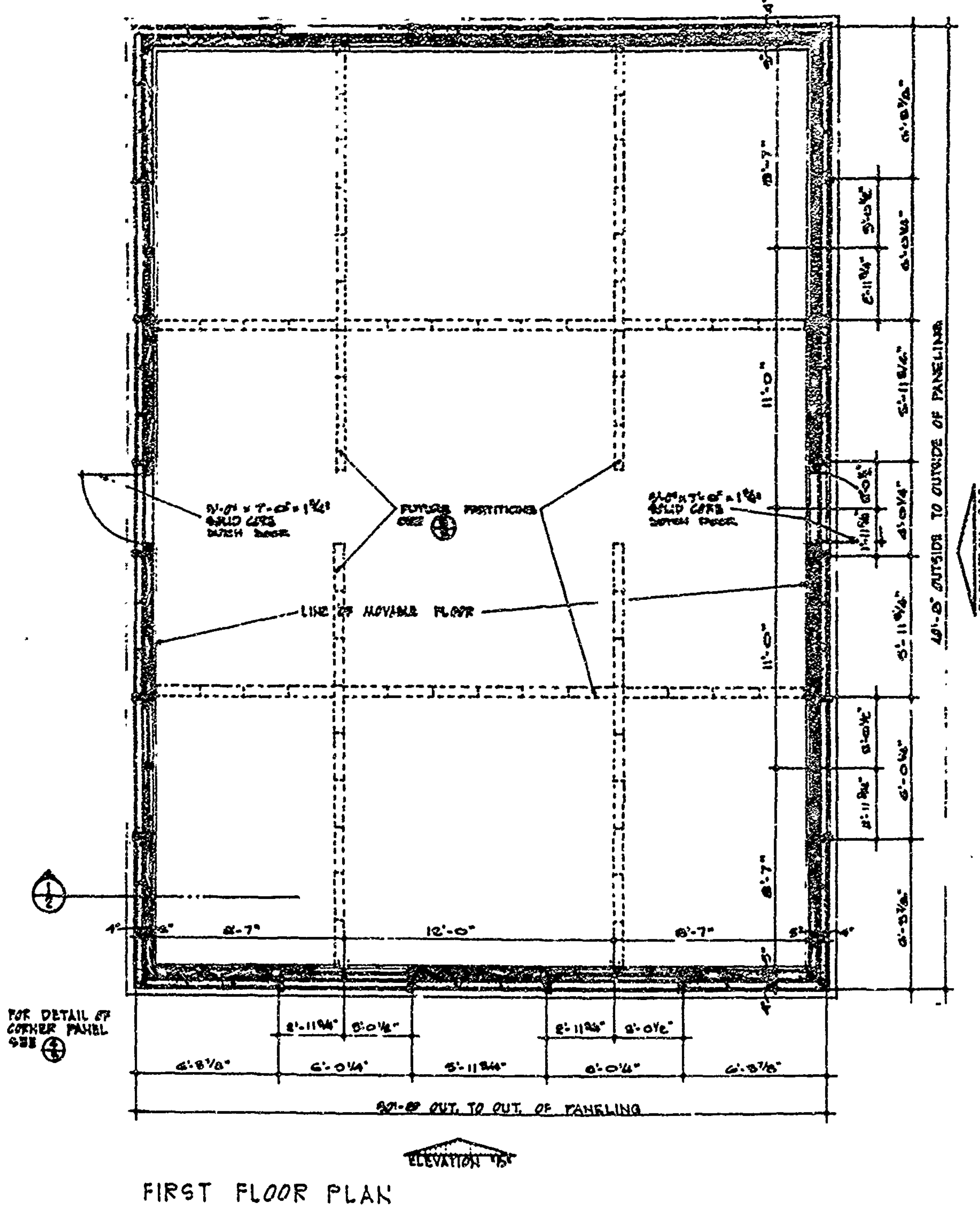


Fig. 2-5. Detailed Test Structure Drawings.



FIRST FLOOR PLAN

Fig. 2-6. Detailed Test Structure Drawings.

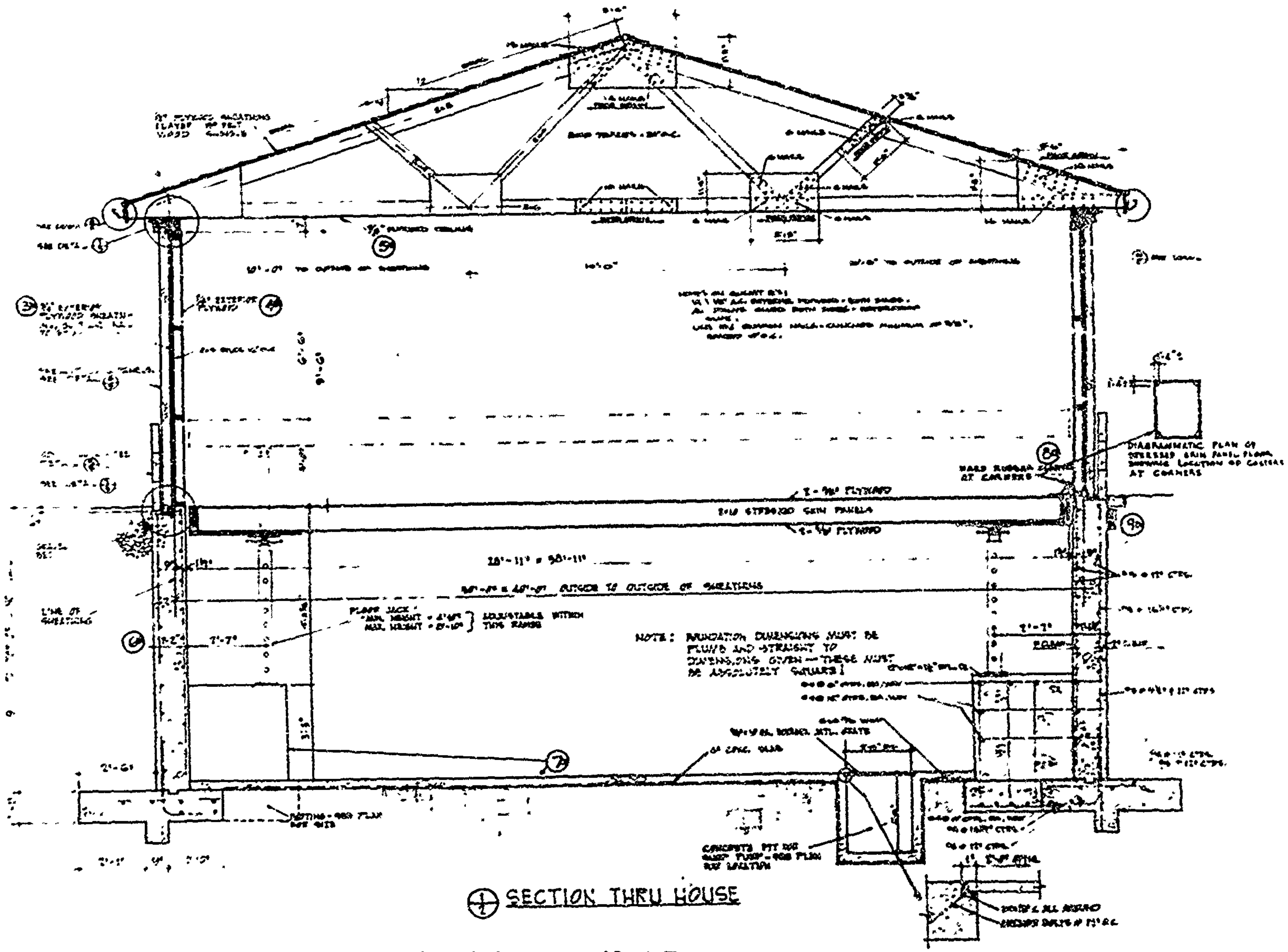


Fig. 2-7. Detailed Test
Structure Drawings.

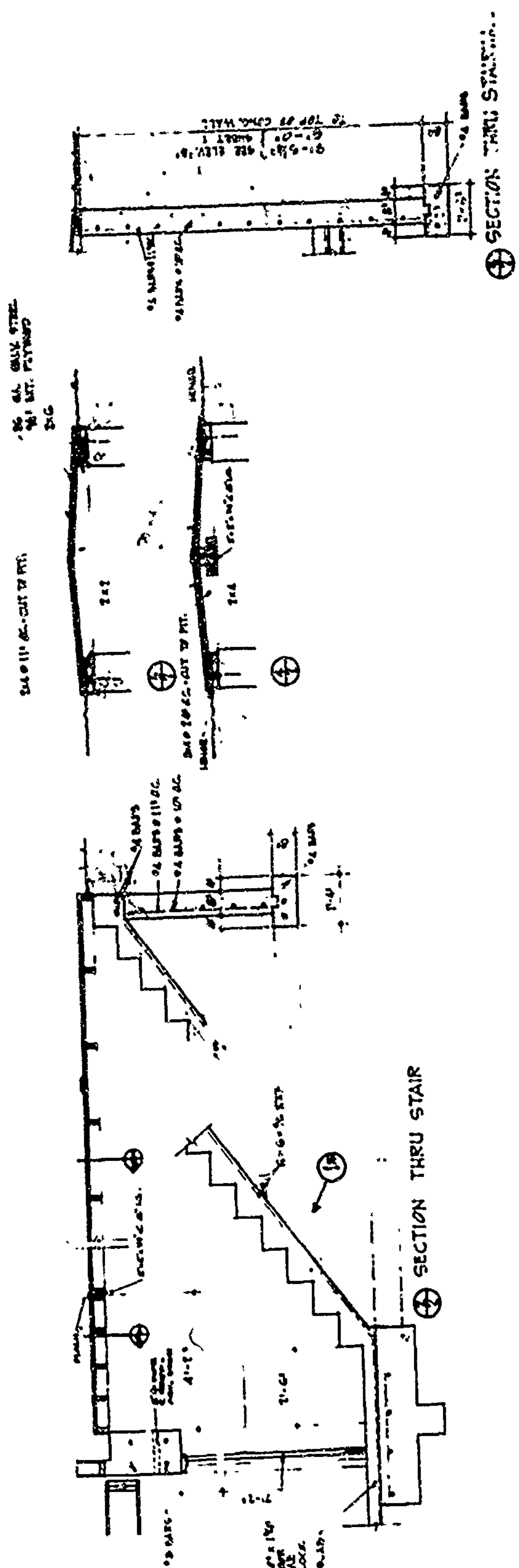


Fig. 2-8. Detailed Test Structure Drawings.

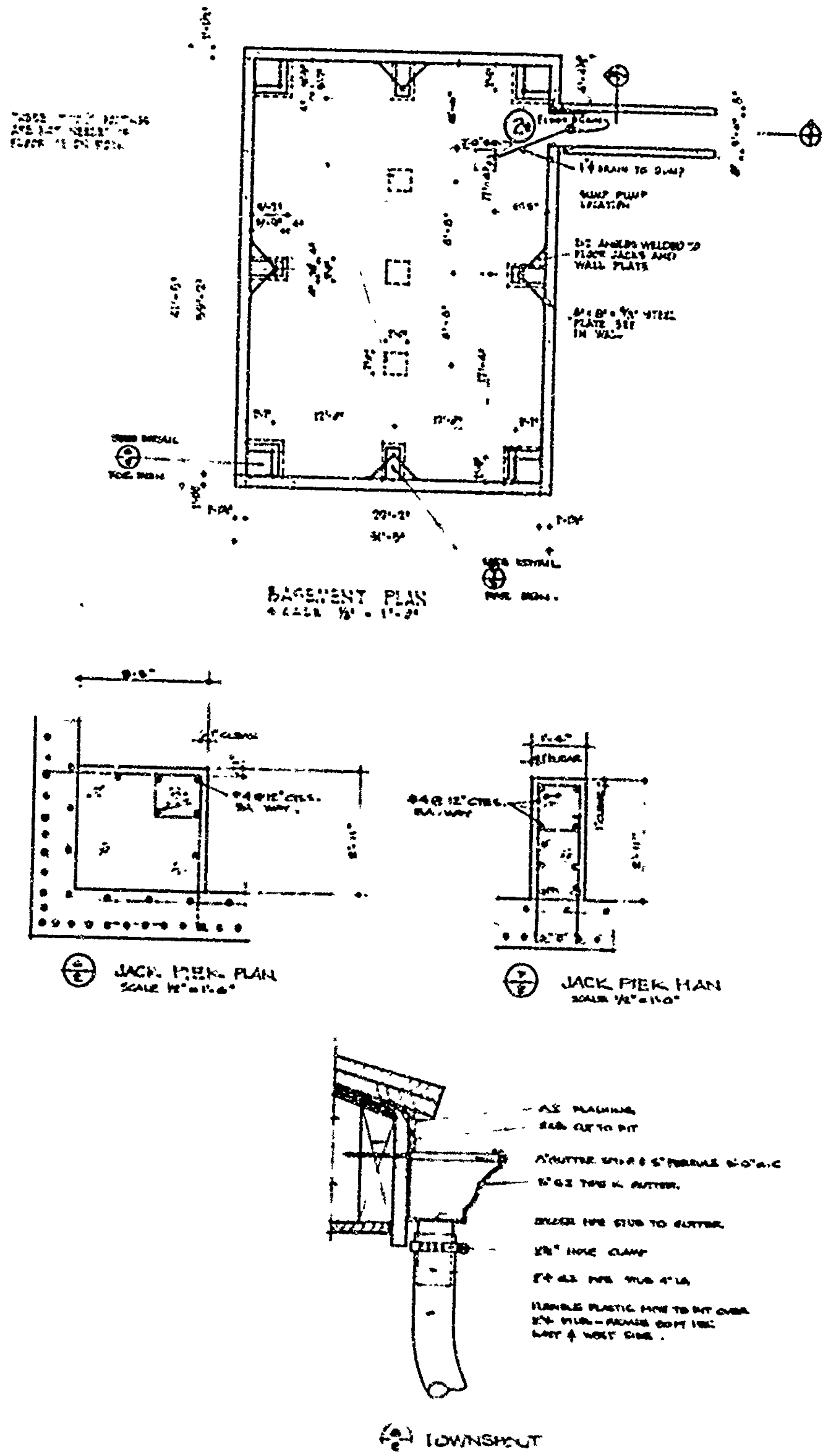
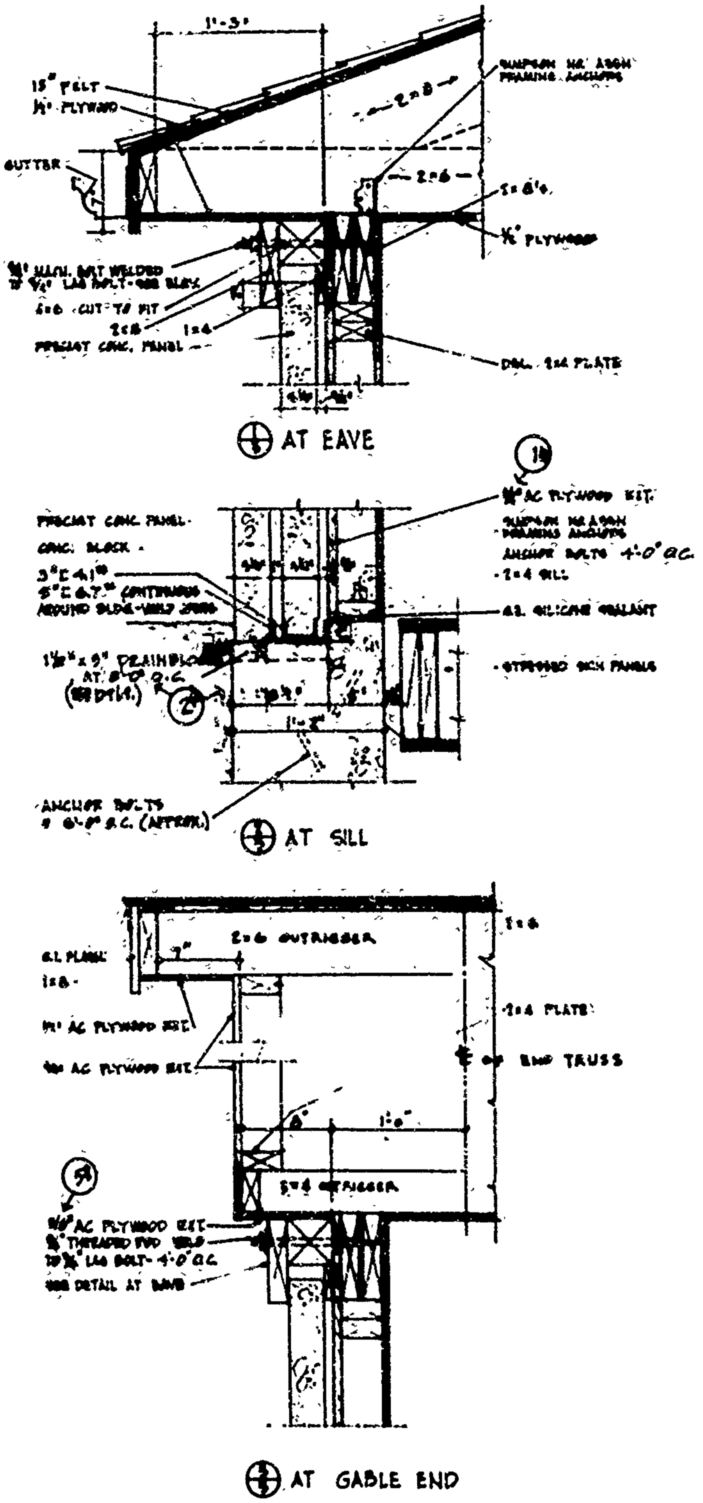
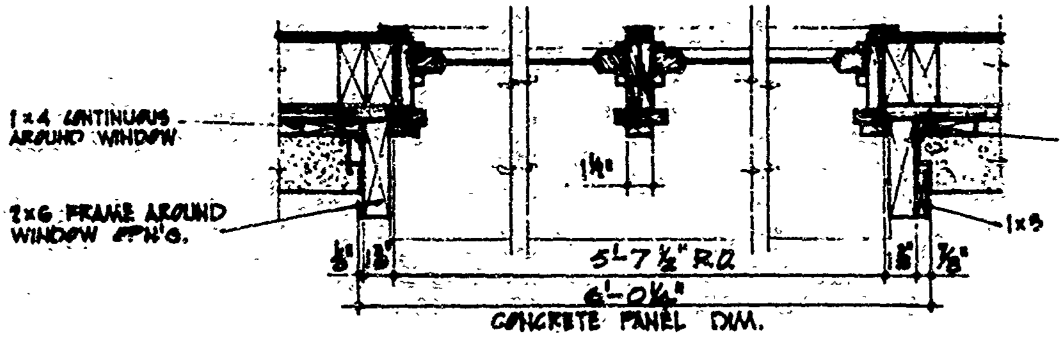


Fig. 2-9. Detailed Test Structure Drawings.

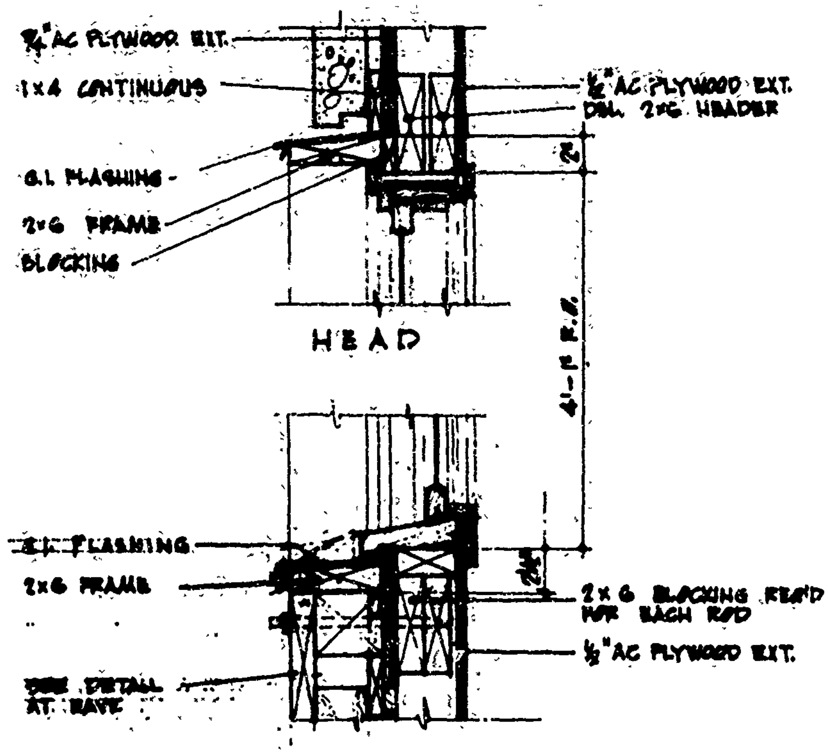


WALL DETAILS

Fig. 2-10. Detailed Test Structure Drawings.



JAMB DETAILS



WINDOW DETAILS

Fig. 2-11. Detailed Test Structure Drawings.

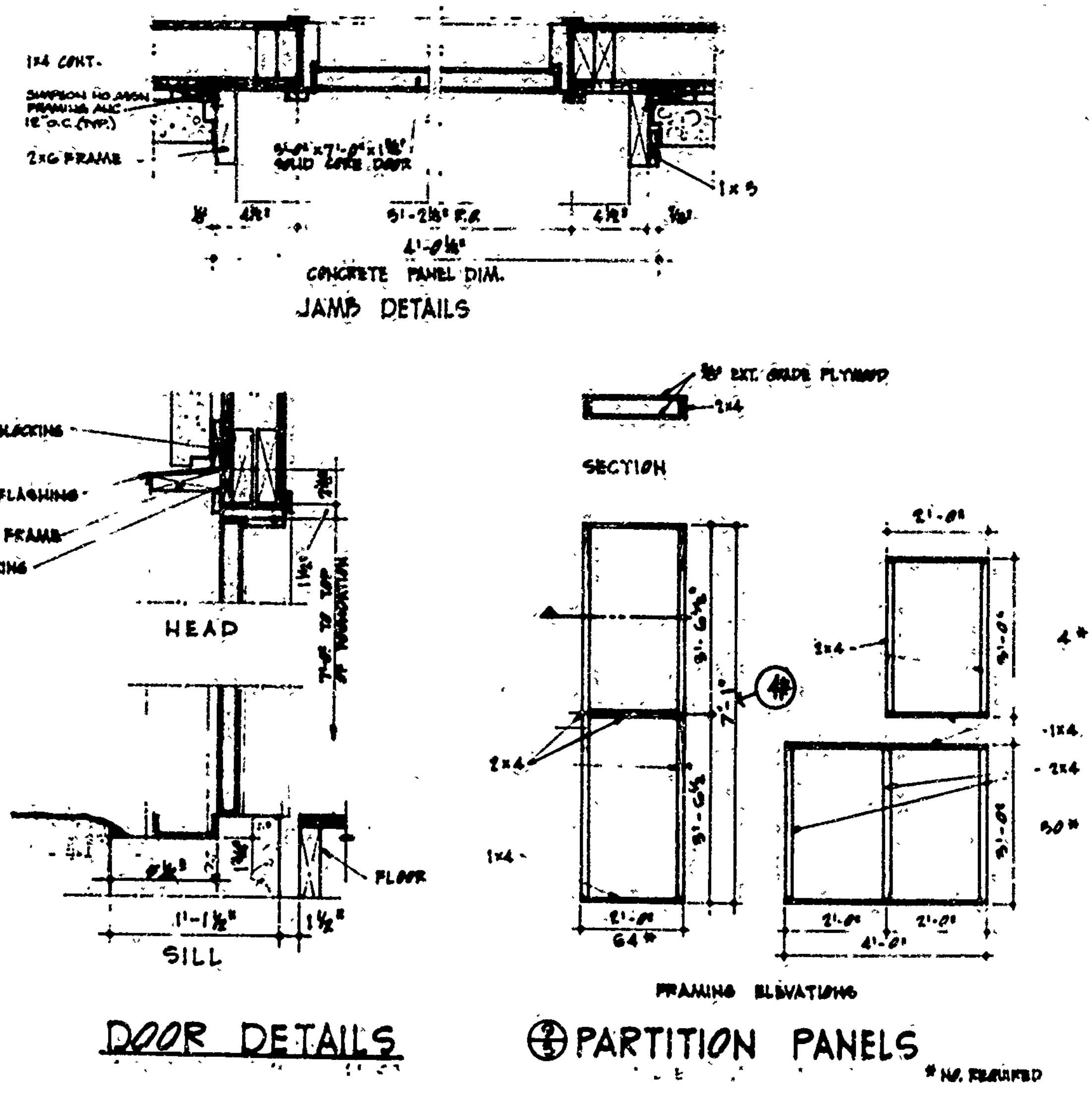


Fig. 2-12. Detailed Test Structure Drawings.

NOT REPRODUCIBLE

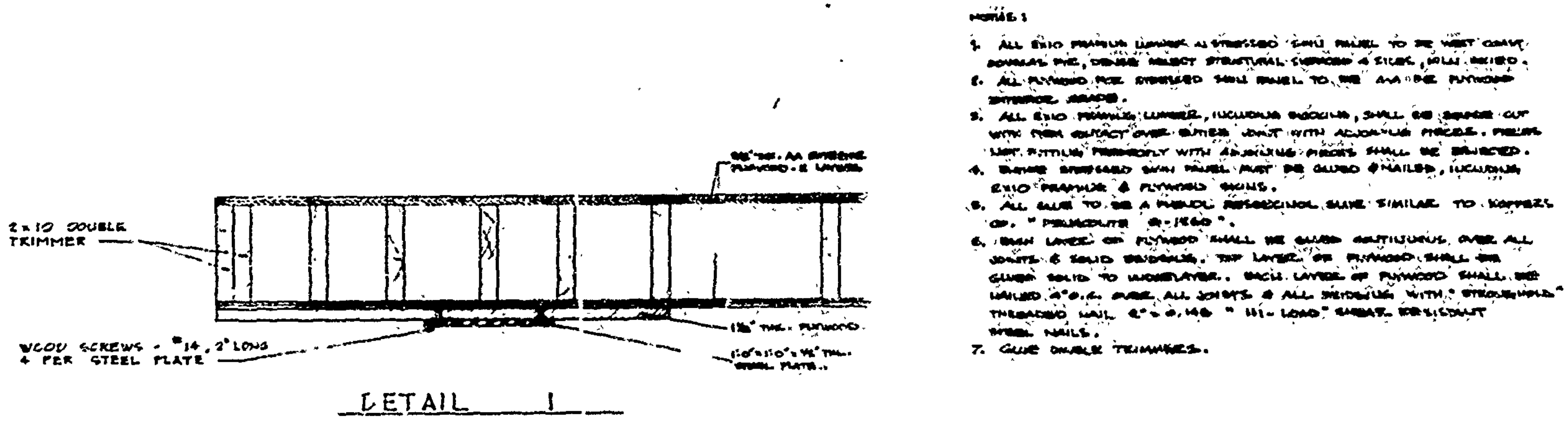


Fig. 2-13. Detailed Test Structure Drawings.

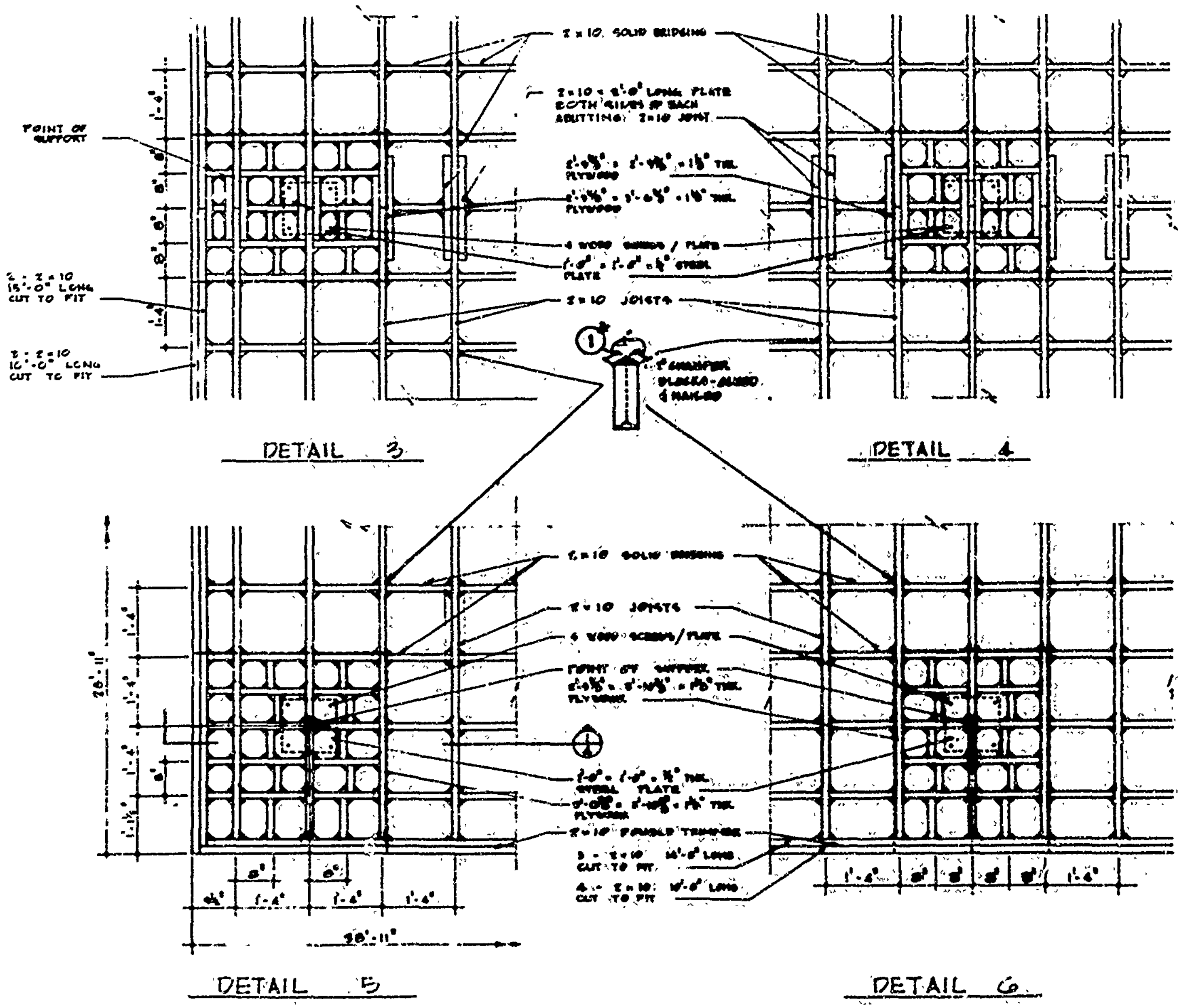
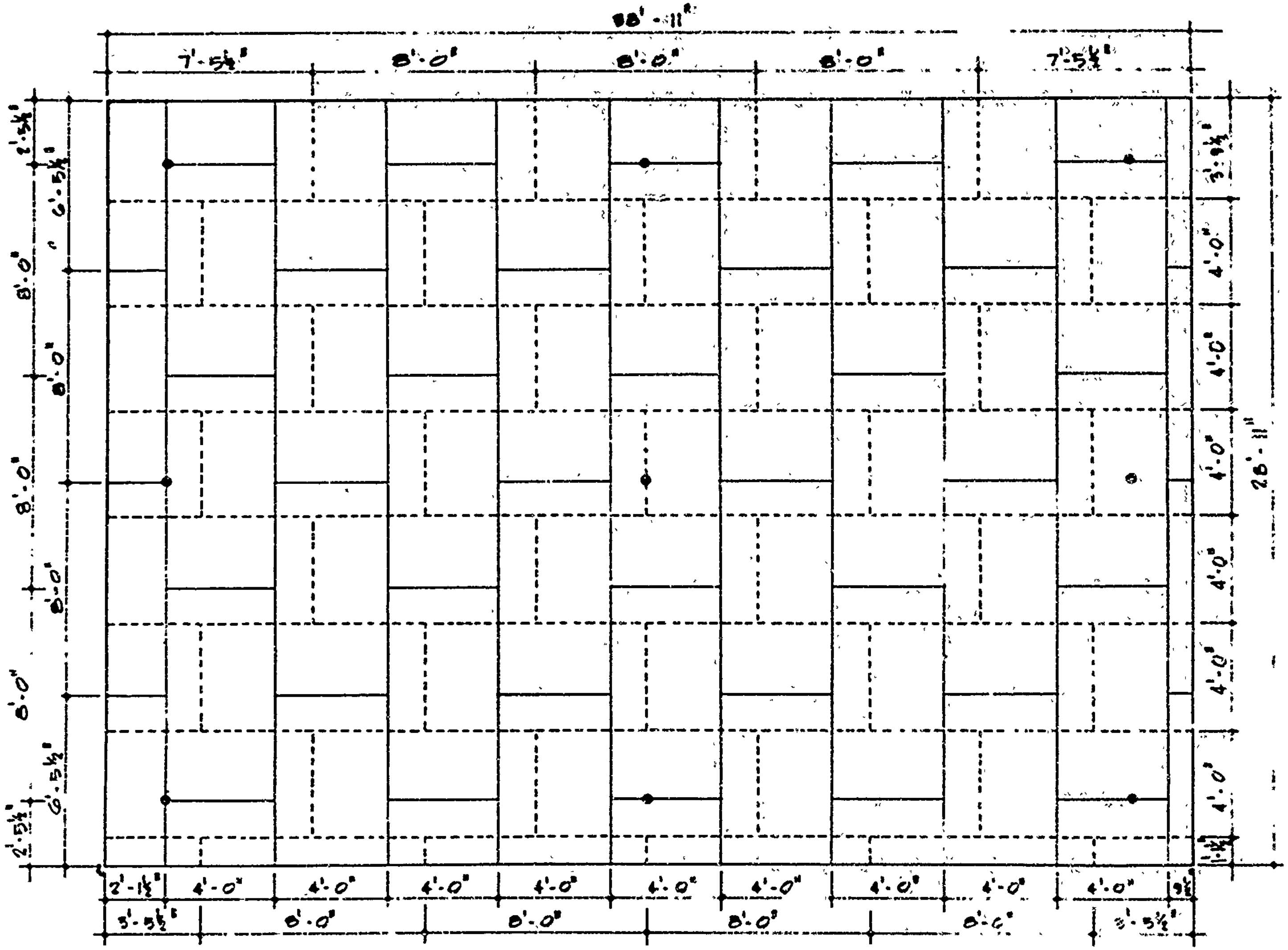


Fig. 2-14. Detailed Test Structure Drawings.



FLOOR LAYOUT OF 3/8" PLYWOOD
SCALE 1/4" = 1'-0"

Fig. 2-15. Detailed Test Structure Drawings.

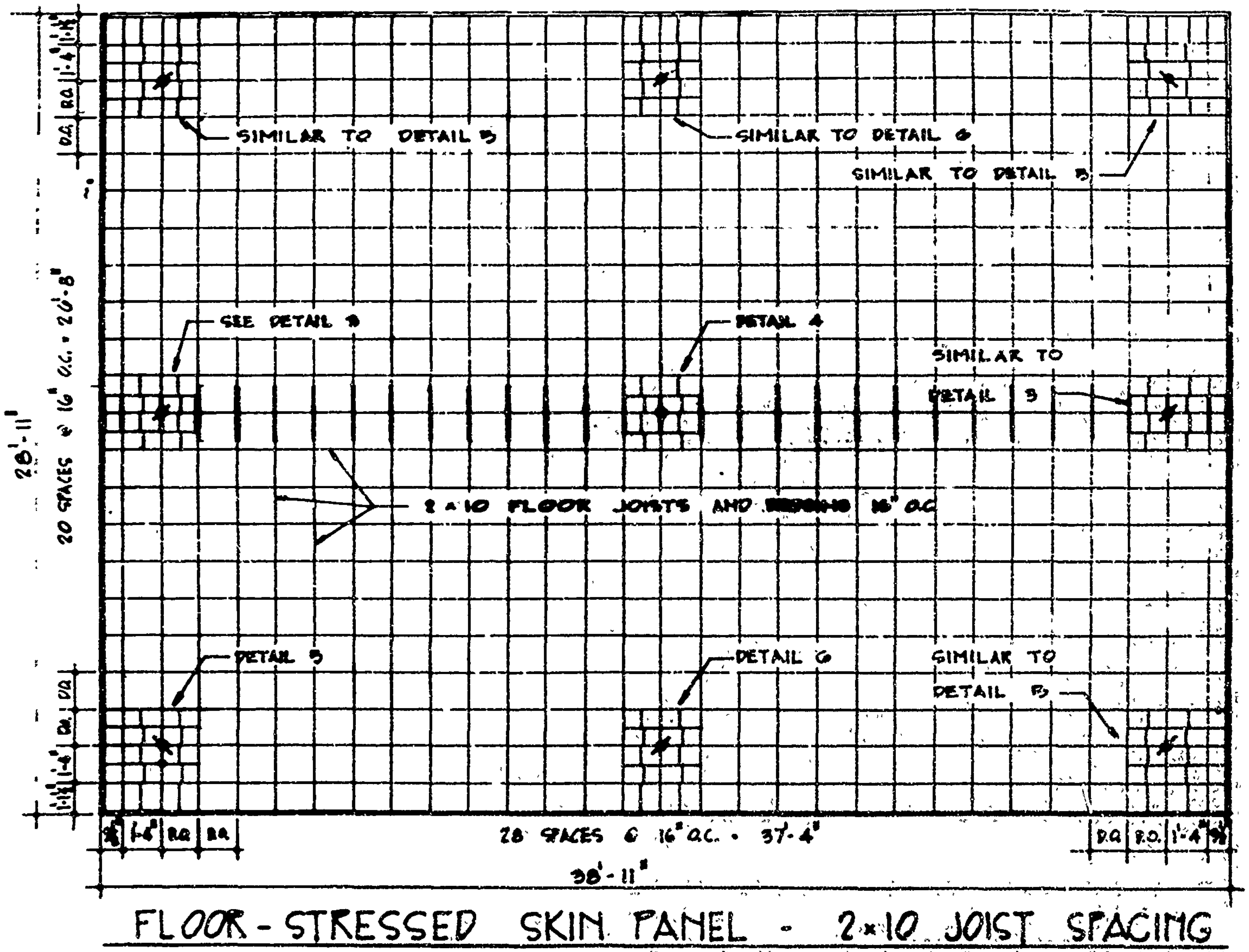


Fig. 2-16. Detailed Test Structure Drawings.

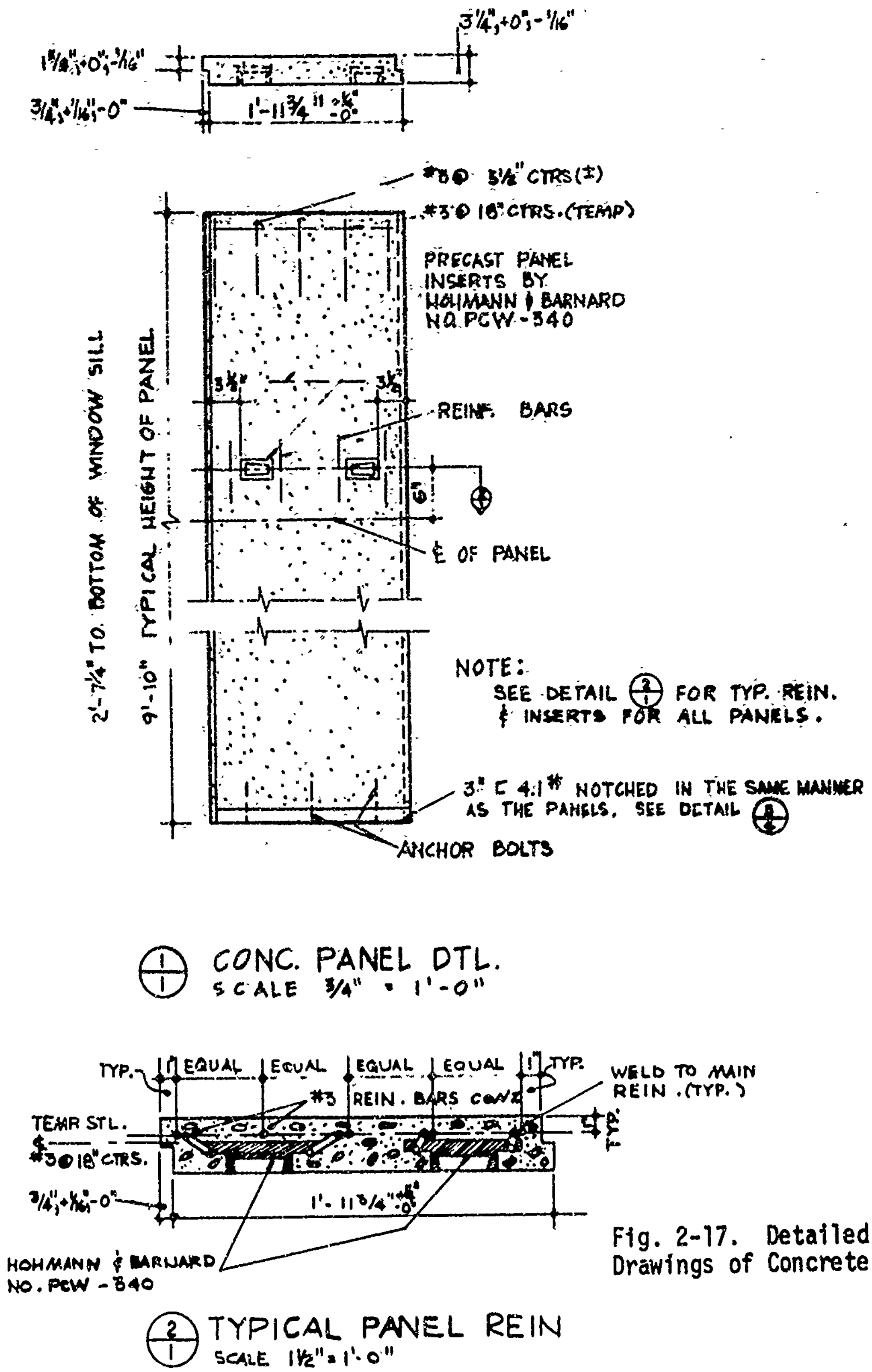


Fig. 2-17. Detailed Drawings of Concrete Panels.

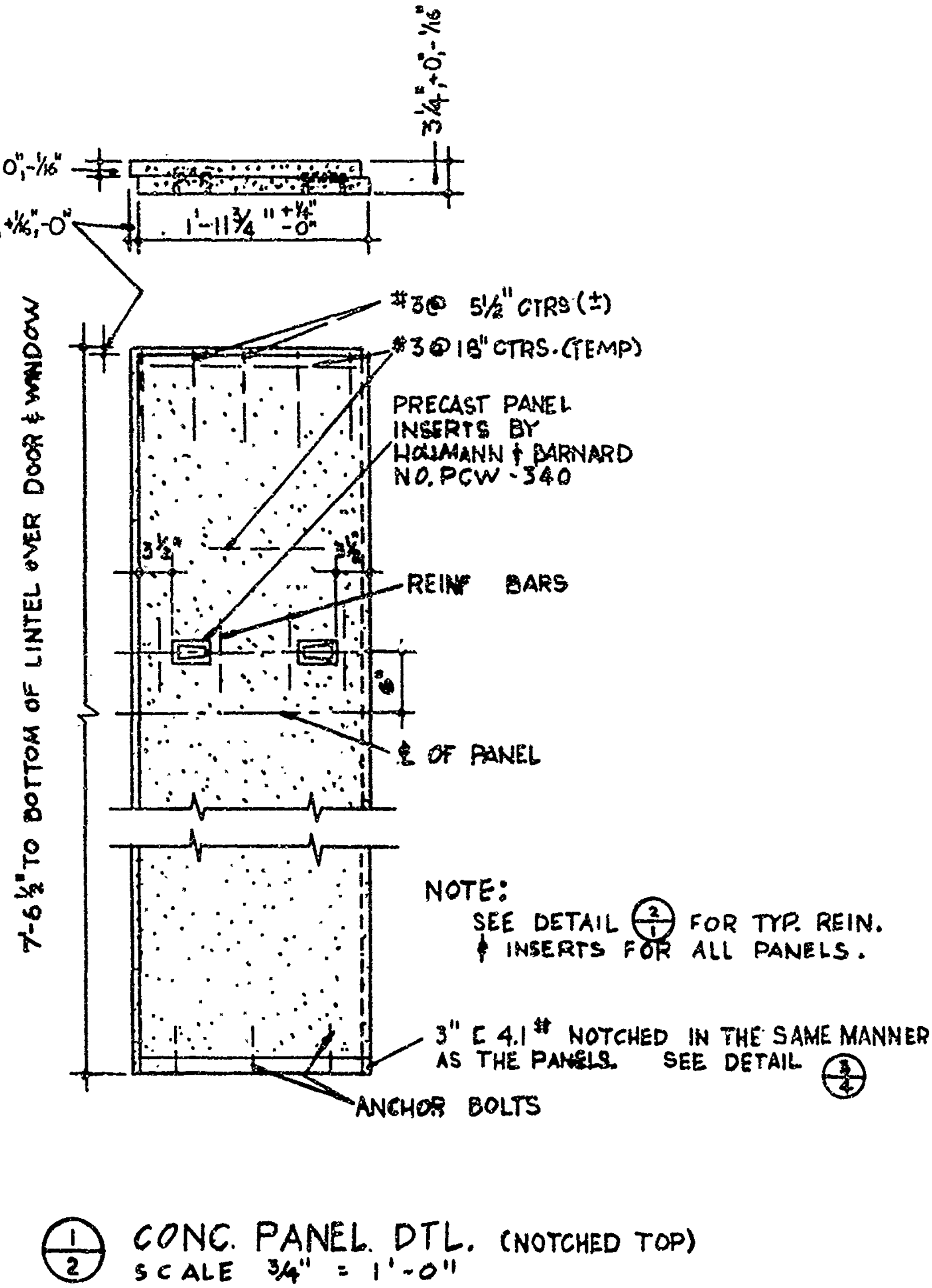


Fig. 2-18. Detailed Drawings of Concrete Panels.

NOT REPRODUCIBLE

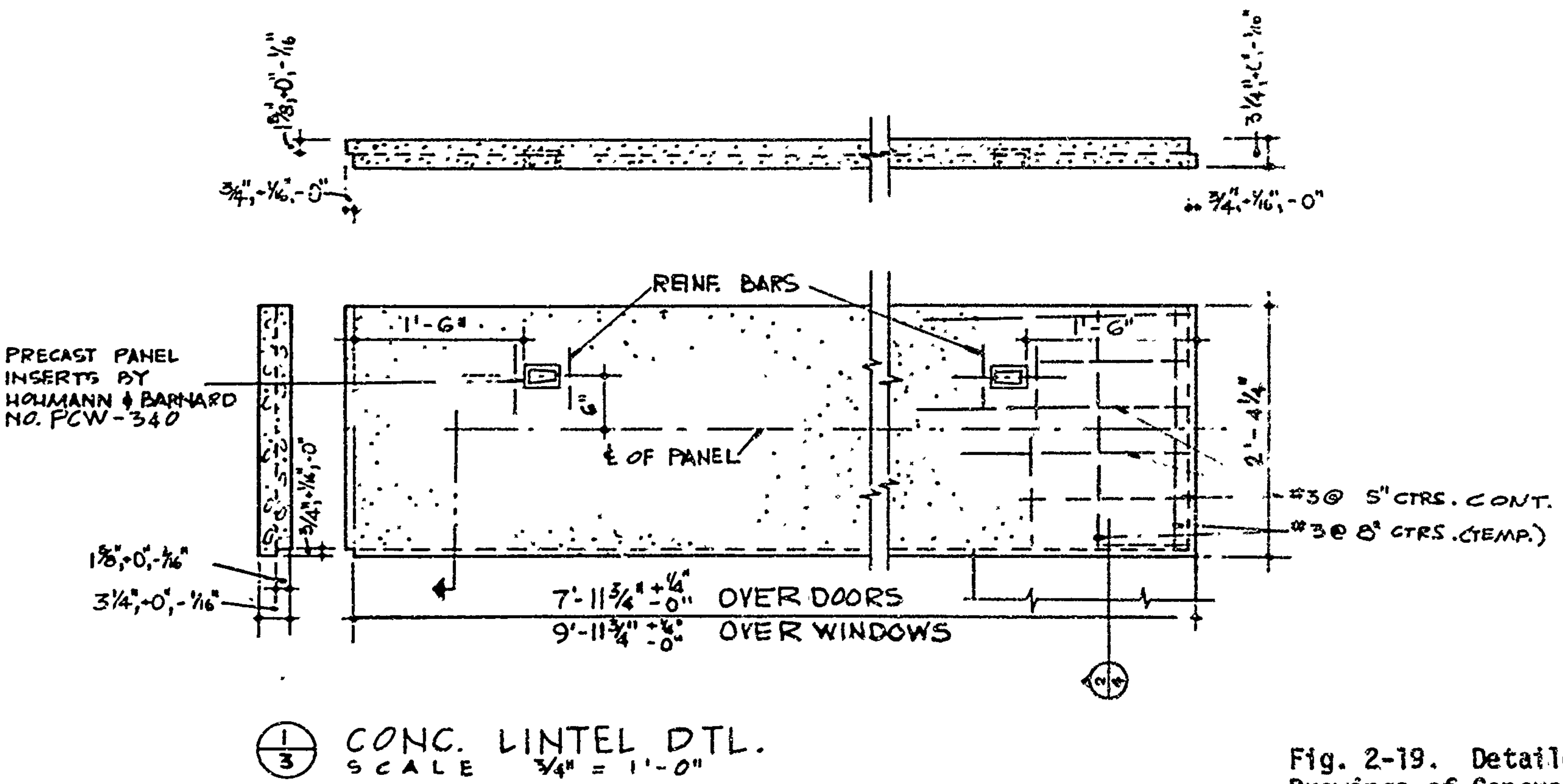


Fig. 2-19. Detailed Drawings of Concrete Panels.

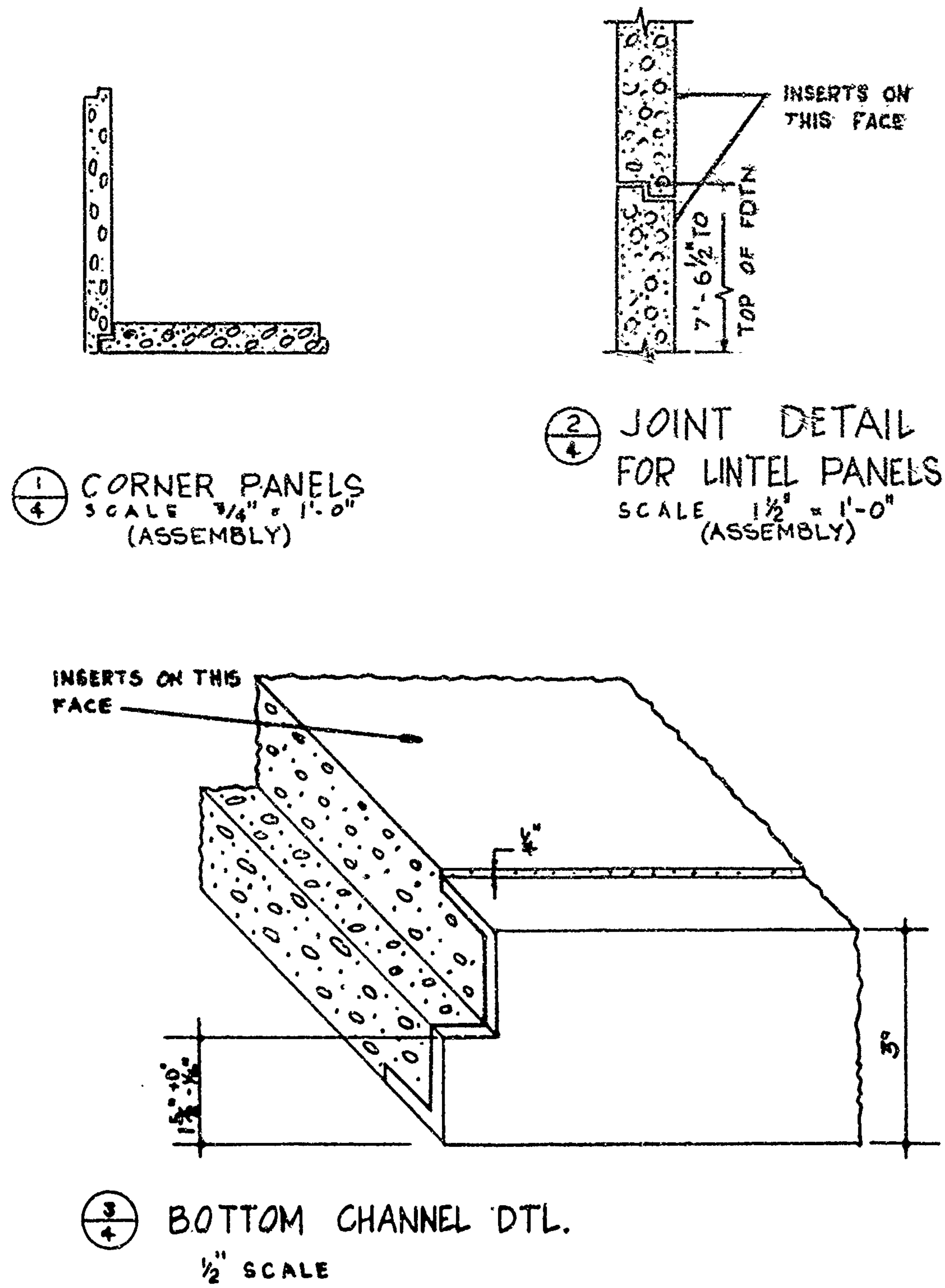


Fig. 2-20. Detailed Drawings of Concrete Panels.

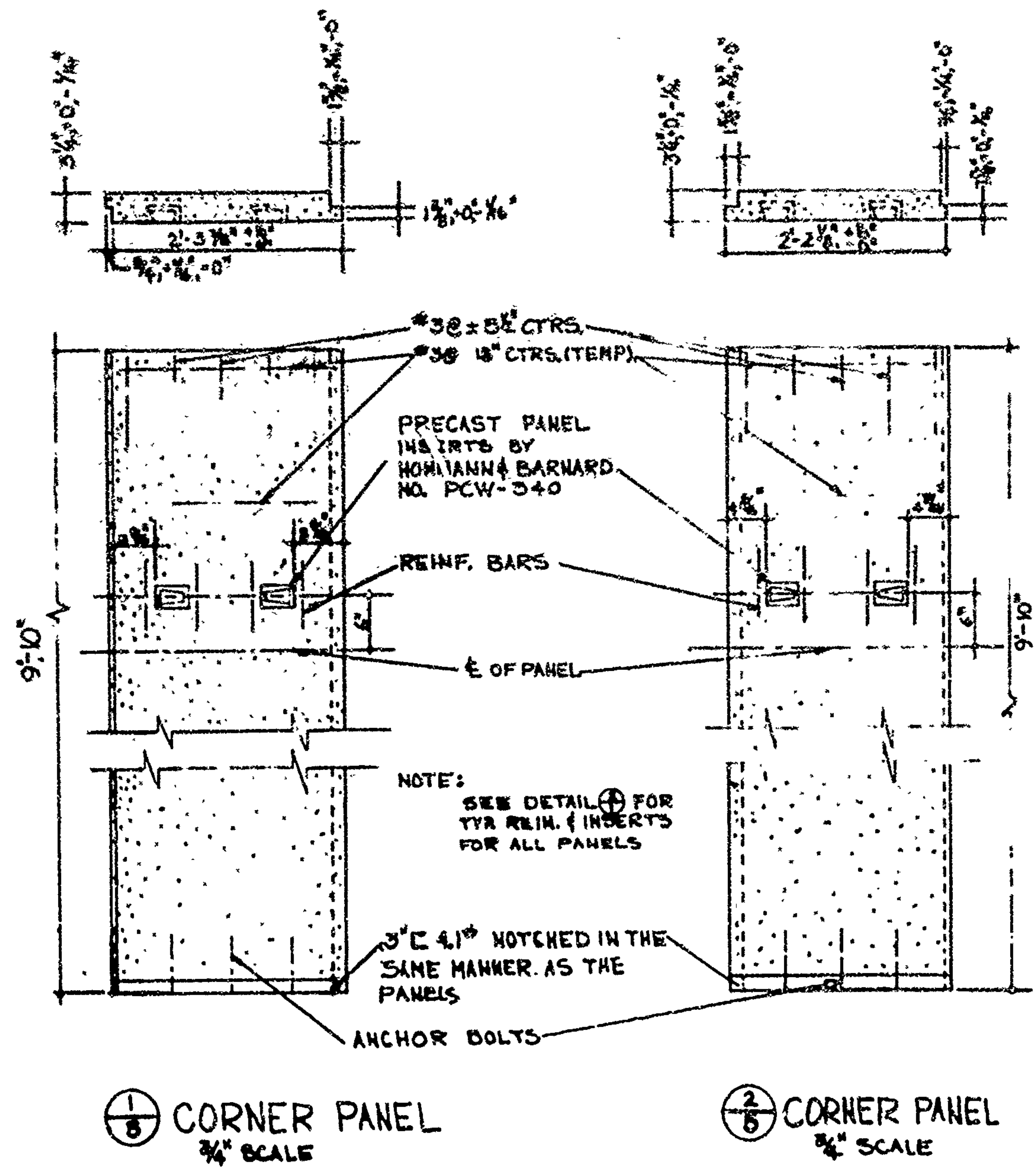
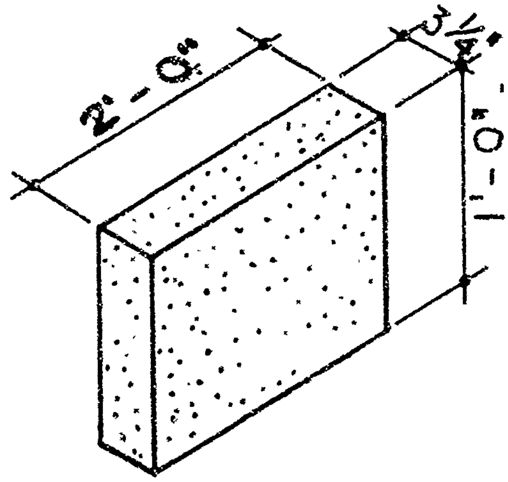


Fig. 2-21. Detailed Drawings of Concrete Panels.



CONC. BLOCK DTL.

ALL DIMENSIONS ± 1/8"

Fig. 2-22. Drawing of Concrete Block.

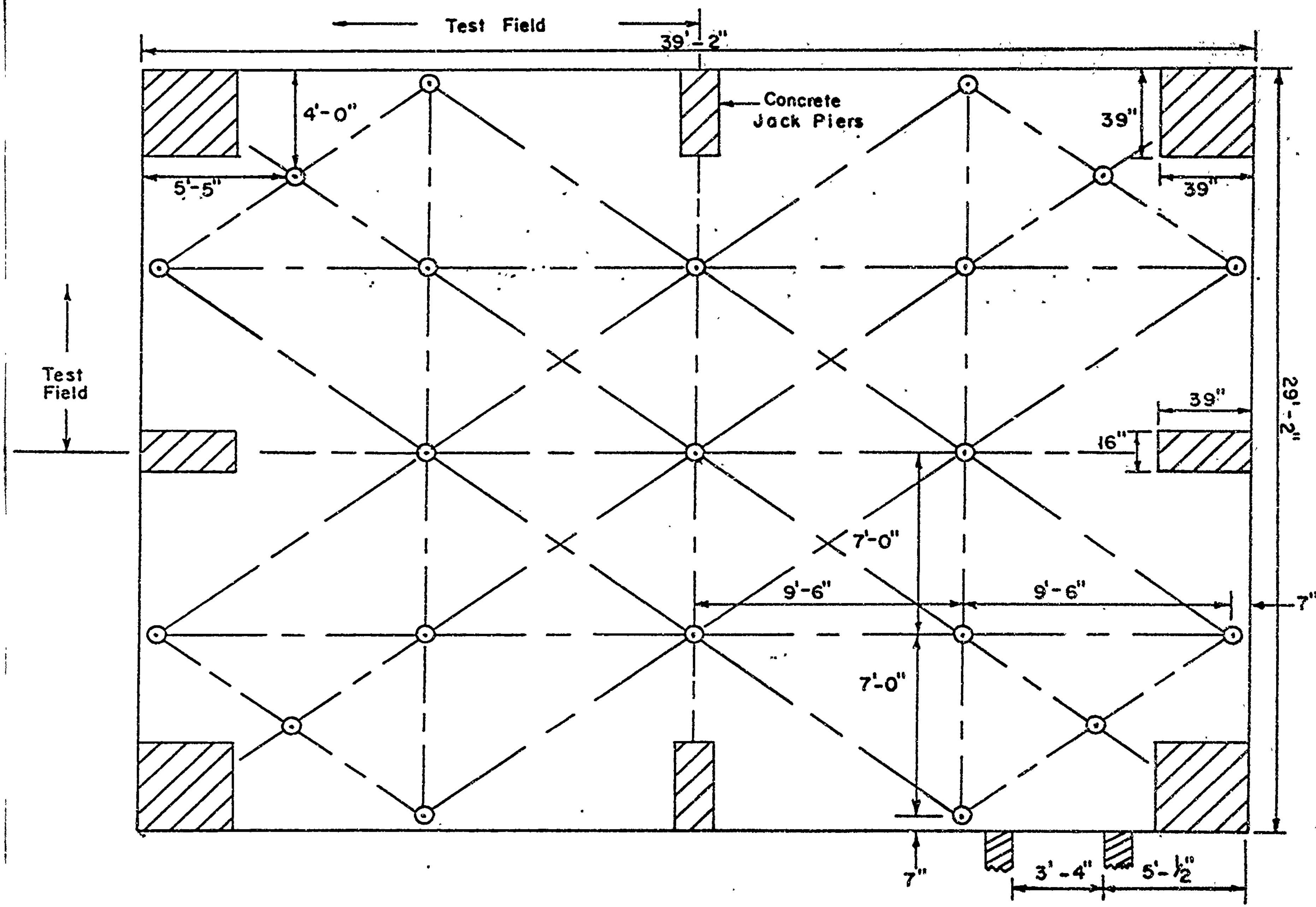


Fig. 2-23. Dosimeter locations in the basement of the test structure.

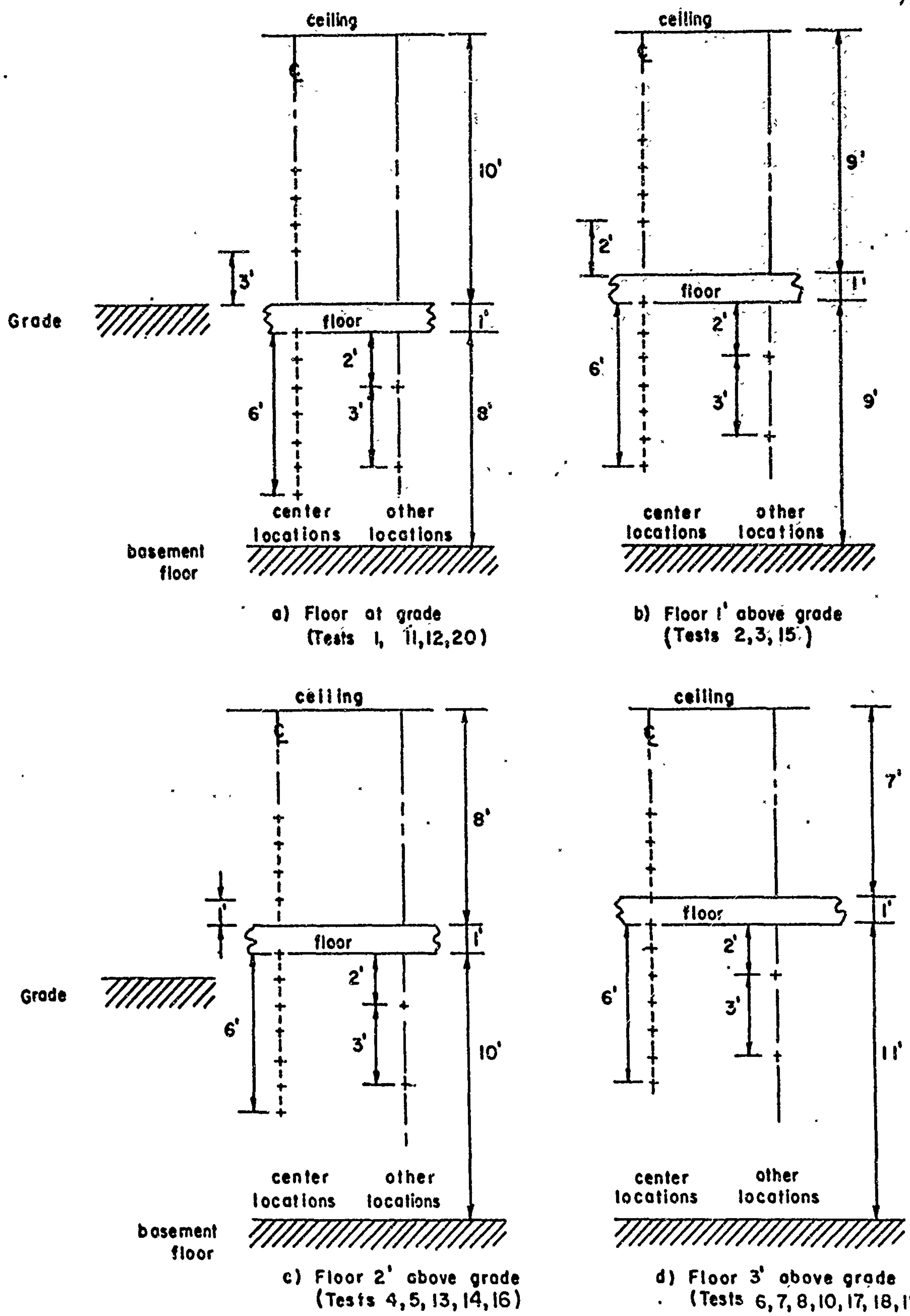


Fig. 2-24. Schematic of detector locations in the test structure.

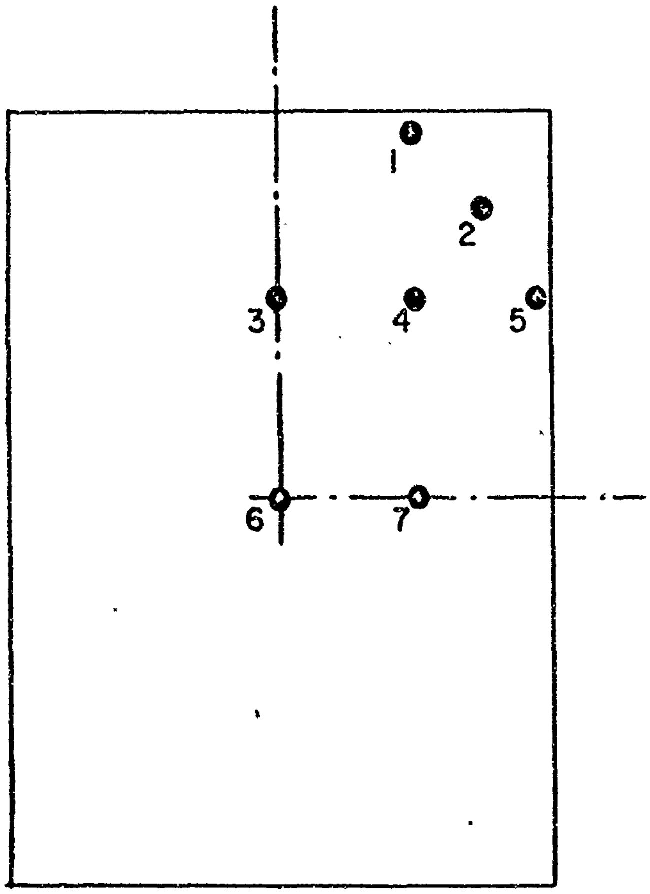


Fig. 2-25. Key to grid point numbers.

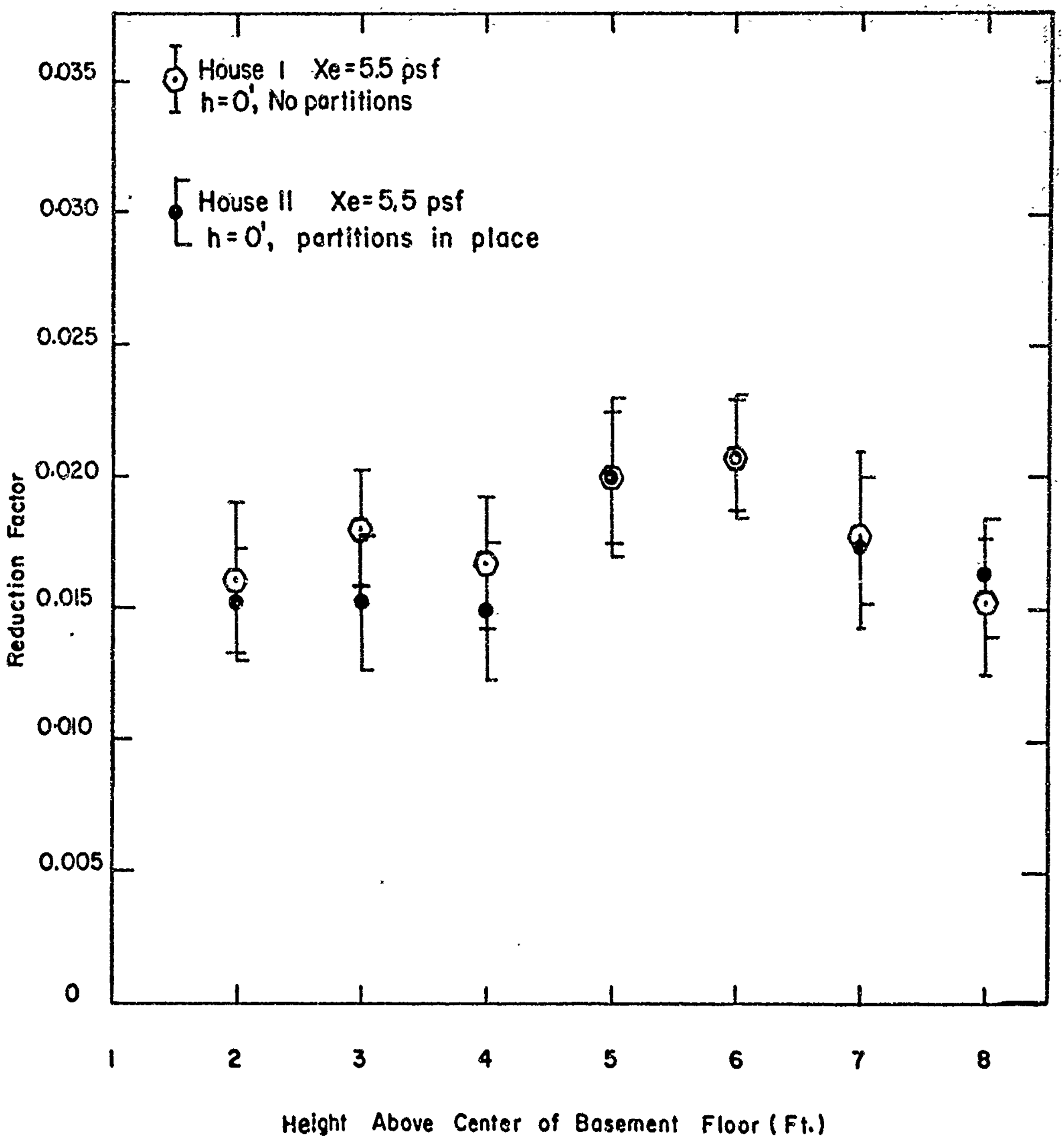


Fig. 4-1. Comparison of experimental basement centerline reduction factors for Houses 1 and 11.

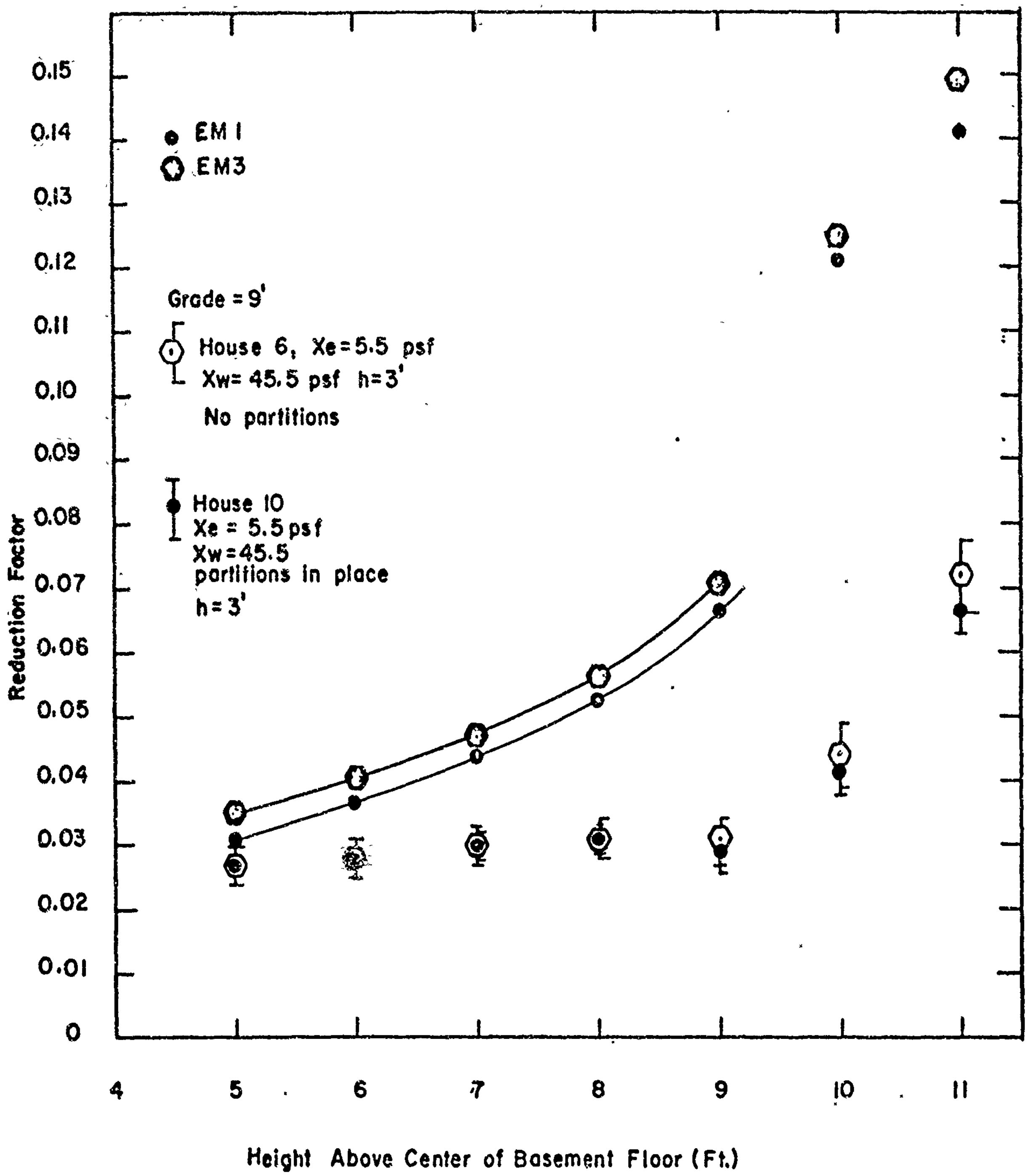


Fig. 4-2. Theoretical and experimental results for Houses 6 and 10 along the basement centerline.

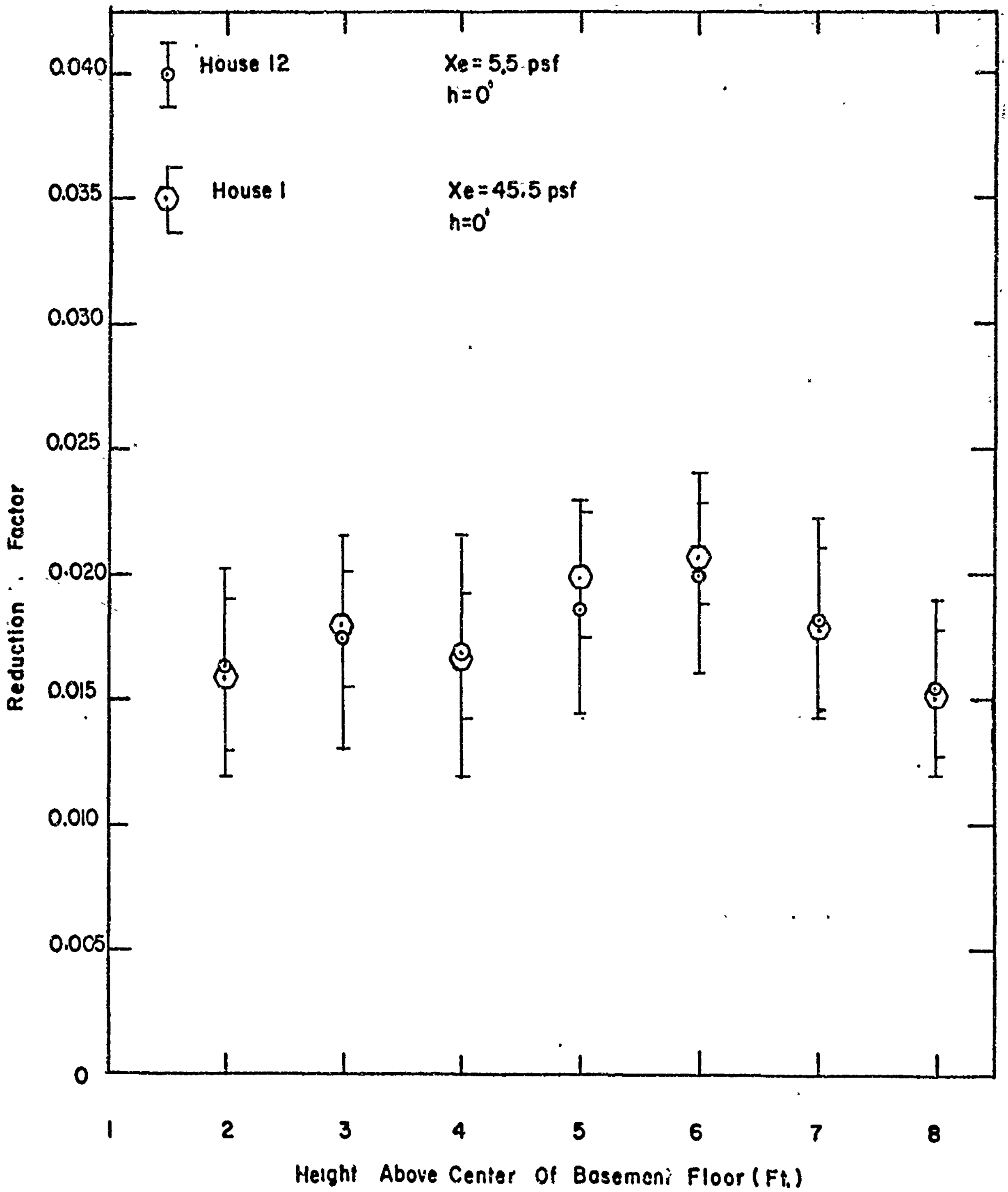


Fig. 4-3. Comparison of experimental results for Houses 1 and 12 along the basement centerline.

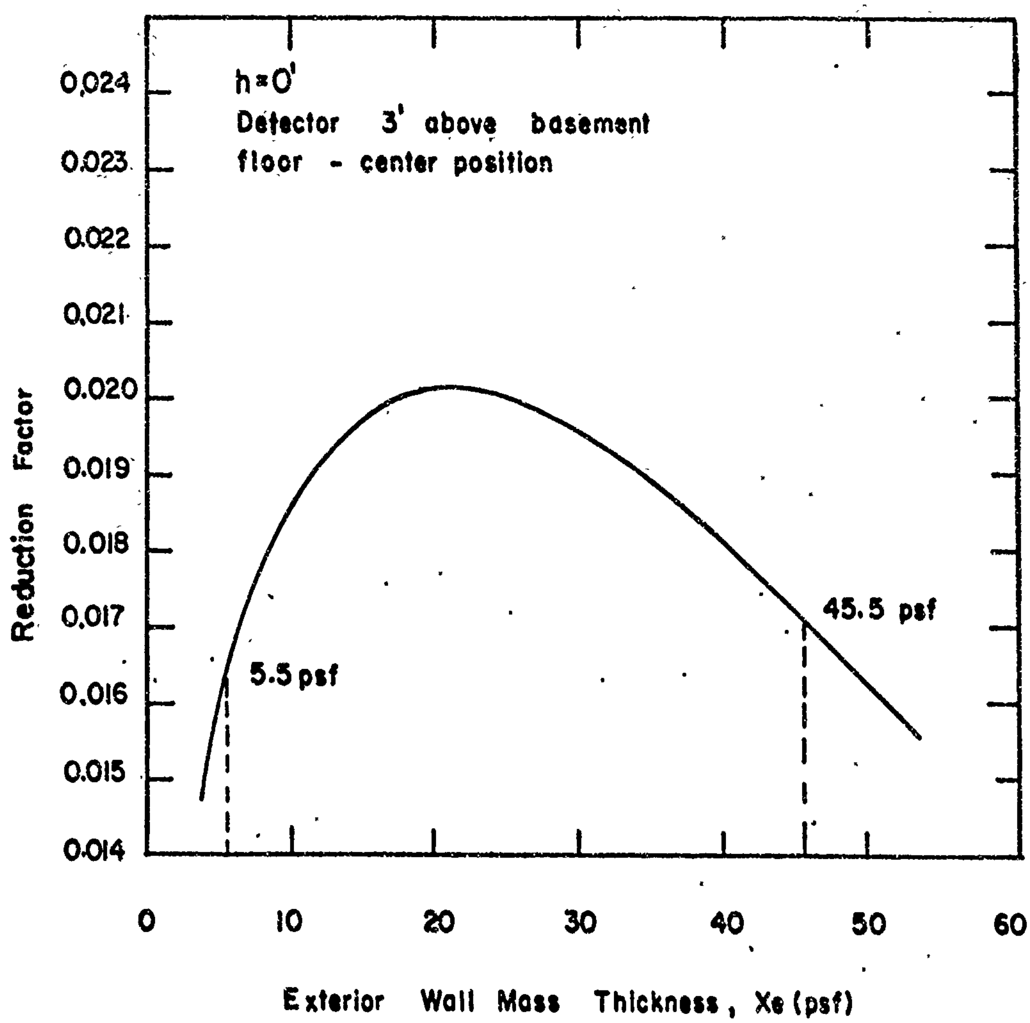


Fig. 4-4. Engineering Manual predictions as a function of exterior wall mass thickness for a detector 3 feet above the basement floor h=0.

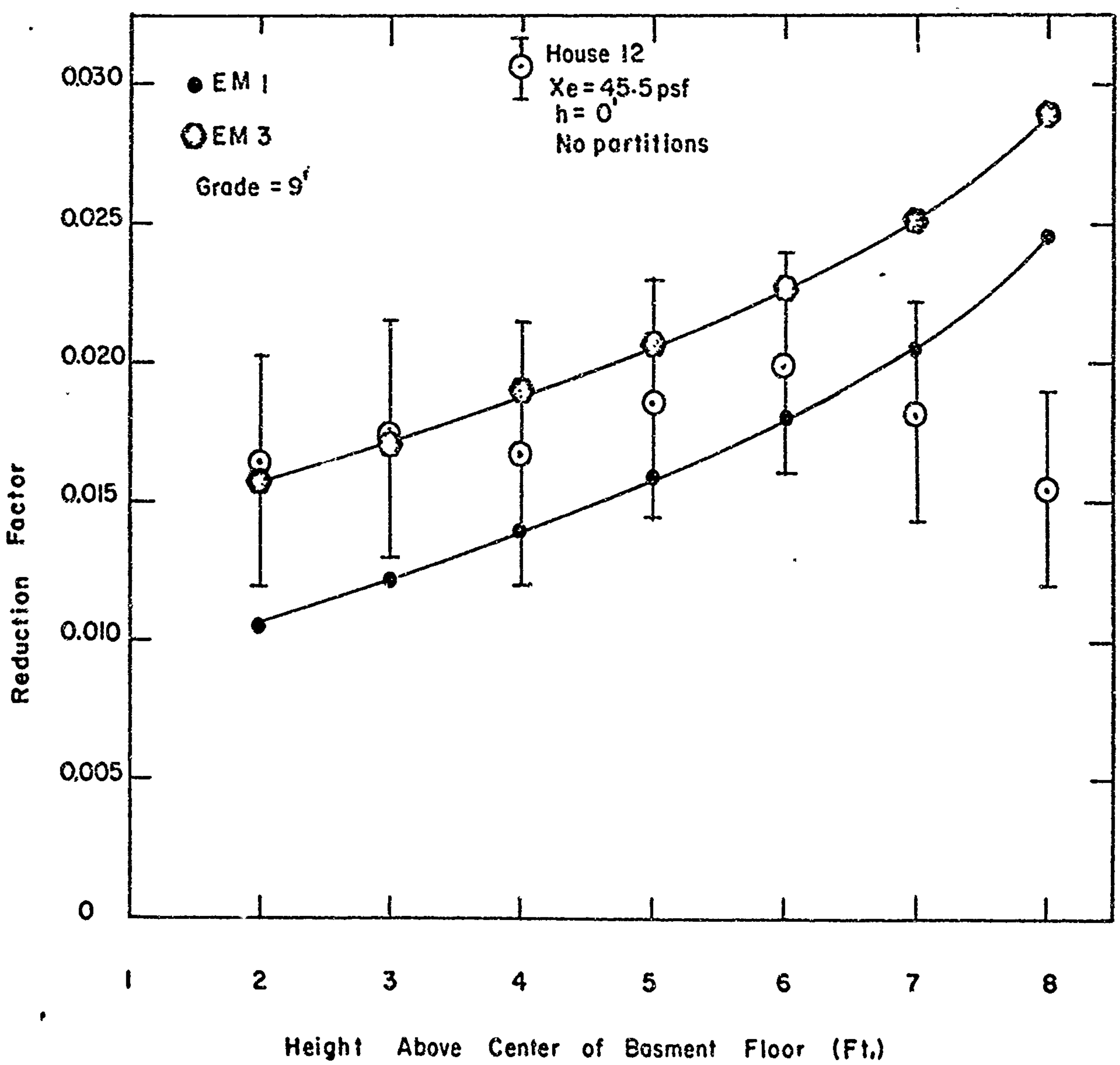


Fig. 4-5. Theoretical and experimental results for House 12 along the basement centerline.

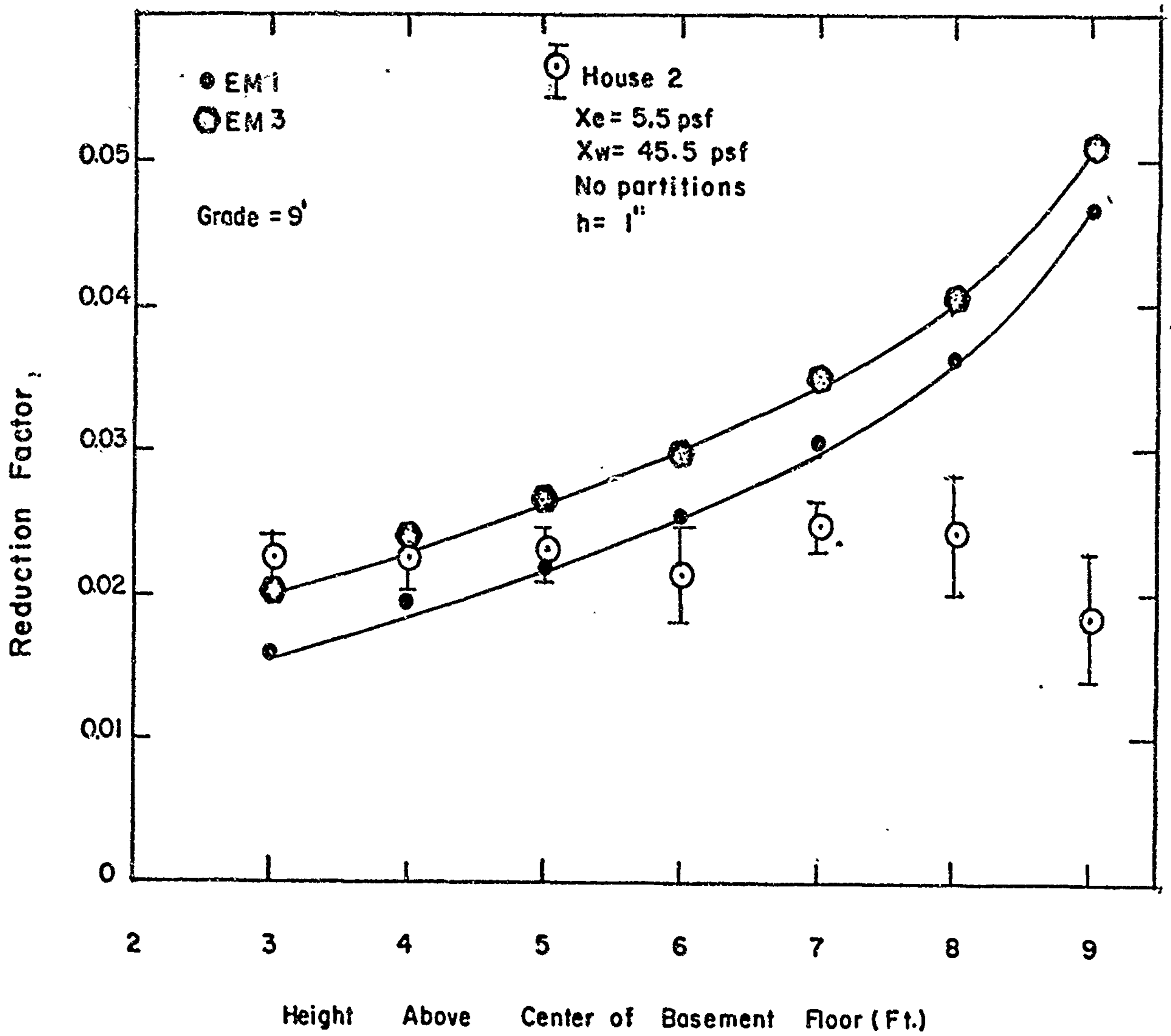


Fig. 4-6. Theoretical and experimental results for House 2 along the basement centerline.

VI. APPENDICES

6.1 Appendix A, Engineering Manual Calculations for the KSUNESF Test House

6.1.1 Introduction

This appendix outlines Engineering Manual (EM) calculations for the KSUNESF test house according to TR-20, Vol. 1 (4). An attempt has been made to stay within the bounds of the EM theory in cases where the procedure was not explicitly described in the EM. A FORTRAN IV program called ENGMAN was written to carry out calculations for almost any combination of detector location and floor height. No explanation of the EM functions is given here; it is assumed that the reader has a knowledge of EM theory. The purpose of this appendix is to document the exact functional expressions used.

6.1.2 Nomenclature

The reduction factor for the ground contribution, C_g, has been separated into three contributions: 1) the contribution from non-structure-scattered radiation reaching the detector from directions below the detector plane; 2) the contribution from non-structure-scattered radiation reaching the detector from directions above the detector plane (air-scattered radiation, or skyshine); and 3) the structure scattered contribution. These contributions are identified with the following superscripts: D, A, S, respectively. The contributions are further broken down according to the various external surfaces of the house through which the radiation passes. These surfaces are as follows: 1) the exposed basement walls, 2) the solid walls of the first story, 3) the windows, 4) the roof, 5) the doors of the first story. They are identified by the following second-superscripts: 1, 2, 3, 4, d, respectively. Thus, C_g^{A3} would be the skyshine contribution through the windows, while C_g^{S1} would be the wall-scattered contribution from the exposed basement walls.

The mass thicknesses of the various barriers in the house are given the following labels: exposed basement walls, X_w; first story walls, X_e; doors, X_d; floor slab, X_f; roof, X_r; and interior partitions, X_i. The mass thickness of the floor slab will always be labeled X_f, regardless of whether the detector is above or below it.

6.1.3 First Story Detector Locations

The most general case is for a detector located above the window sill height and below the top of the windows. Refer to Figures A-1 and A-2 for dimensions and solid angles. Note that P_a, the "perimeter ratio", is actually an azimuthal sector as defined in Figure A-1. Note also that the doors are considered in a separate azimuthal sector. Refer to Figure A-3 for the fictitious building used to determine the contribution through the doors. The functional expressions and diagrams below are for a detector located on the centerline of the house. Applications to off-center locations will be discussed later.

$$C_g^{D1} = [G_d(\omega_\ell',H) - G_d(\omega_\ell,H)][1-S_w(X_w)]B_e(X_w,H)B_f(X_f) \tag{A-1}$$

$$C_g^{S1} = [G_s(\omega_\ell') - G_s(\omega_\ell)]\ S_w(X_w)\ E(e)\ B_e(X_w,H)\ B_f(X_f) \tag{A-2}$$

$$C_g^{D2} = \{[G_d(\omega_\ell,H) - G_d(\omega_{a\ell},H)][1-A_{z_D}] + G_d(\omega_{a\ell},H)[1-P_a-A_{z_D}]\}$$

$$\times\ [1-S_w(X_e)]B_e(X_e,H) \tag{A-3}$$

$$= \{G_d(\omega_\ell,H)[1-A_{z_D}] - P_a\ G_d(\omega_{a\ell},H)\}[1-S_w(X_e)]B_e(X_e,H)$$

$$C_g^{S2} = \{[G_s(\omega_u) - G_s(\omega_{a\ell})] + [G_s(\omega_\ell) - G_s(\omega_{a\ell})][1-A_{z_D}]$$

$$+\ [G_s(\omega_{au}) + G_s(\omega_{a\ell})][1-P_a-A_{z_D}]\}\ S_w(X_e)E(e)\ B_e(X_e,H) \tag{A-4}$$

$$= \{G_s(\omega_u) - G_s(\omega_{au})\ [P_a + A_{z_D}] - P_a\ G_s\ (\omega_{a\ell}) + G_s(\omega_\ell)[1-A_{z_D}]\}$$

$$\times\ S_w(X_e)\ E(e)\ B_e(X_e,H)$$

$$C_g^{A2} = \{G_a(\omega_u) - G_a(\omega_{au})[P_a + A_{z_D}]\}[1-S_w(X_e)]B_e(X_e,H) \tag{A-5}$$

$$C_g^{D3} = G_d\ (\omega_{a\ell},H)\ P_a\ B_e(0,H) \tag{A-6}$$

$$C_g^{A3} = G_a(\omega_{au})\ P_a\ B_e(0,H) \tag{A-7}$$

$$C_g^{A4} = A_a(\omega_u)\ B_o'(X_r)^* \tag{A-8}$$

$$C_g^{Dd} = G_d(\omega_\ell,H)\ [1-S_w(X_d)]B_e(X_d,H)\ A_{z_D} \tag{A-9}$$

$$C_g^{Sd} = [G_s(\omega_\ell) + G_s(\omega_{au})]\ S_w(X_d)E(e)\ B_e(X_d,H)\ A_{z_D} \tag{A-10}$$

$$C_g^{Ad} = G_a(\omega_{au})[1-S_w(X_d)]\ B_e(X_d,H)\ A_{z_D} \tag{A-11}$$

It was determined that the wall-scattered contribution from the gable walls was at most one percent of the total contribution. Hence, the flat roof configuration of Figure A-2 is justified.

Note that Eq. (A-8) is the expression for a decontaminated roof contribution for below grade detector locations. It is used here as the best approximation for the skyshine contribution through the roof since the detector heights are small.

For the cases when the detector is below the sill height, the contribution through the first story walls and windows are slightly different. Refer to Figure A-4.

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* This is the notation of the May, 1964, edition of the Engineering Manual and is most common in the literature. In the July, 1968 edition the floor barrier factor is labeled $B_c(X)$.

$$C_g^{D2} = G_d(\omega_\ell, 3') \; [1-S_w(X_e)]B_e(X_e, 3')[1-A_{z_D}] \tag{A-12}$$

$$C_g^{S2} = \{G_s(\omega_u)-G_s(\omega_{au}) + [G_s(\omega_\ell) + G_s(\omega_{a\ell})][1-A_{z_D}]$$

$$+ [G_s(\omega_{au}) - G_s(\omega_{a\ell})][1-P_a-A_{z_D}]\}S_w(X_e)E(e)B_e(X_e, 3') \tag{A-13}$$

$$= \{G_s(\omega_u) -G_s(\omega_{au})[P_a + A_{z_D}] + G_s(\omega_{a\ell})P_a + G_s(\omega_\ell)[1-A_{z_D}]$$

$$\times S_w(X_e)E(e)B_e(X_e, 3')$$

$$C_g^{A2} = \{G_a(\omega_u) - G_a(\omega_{au}) + G_a(\omega_{a\ell})[1-A_{z_D}] + [G_a(\omega_{au}) - G_a(\omega_{a\ell})]$$

$$\times [1-P_a-A_{z_D}]\} \quad [1-S_w(X_e)] \; B_e(X_e, 3') \tag{A-14}$$

$$= \{G_a(\omega_u) - G_a(\omega_{au})[P_a + A_{z_D}] + P_aG_a(\omega_{a\ell})\}[1-S_w(X_e)]B_e(X_e, 3')$$

$$C_g^{D3} = 0 \tag{A-15}$$

$$C_g^{A3} = [G_a(\omega_{au}) - G_a(\omega_{a\ell})]P_aB_e(0, 3') \tag{A-16}$$

6.1.4 Case with Interior Partitions

The configuration for the interior partitions is shown in Fig. A-5. The azimuthal sectors containing zero, one, and two partitions are also defined in Fig. A-5. A separate azimuthal aperture fraction P_a, is defined for each sector. This factor is defined as the ratio of the azimuthal angle subtended by the windows in the sector to the total azimuthal angle of the sector in question.

Sector A:

$$A_{z_A} = \frac{10.93}{90} = 0.121 \; ; \quad P_{a_A} = 0$$

Sector B:

$$A_{z_B} = \frac{8.18 + 9.63 + 8.53 + 8.17}{90} = 0.383$$

$$P_{a_B} = \frac{8.18 + 8.17}{34.52} = 0.474$$

Sector C:

$$A_{z_C} = \frac{7.53 + 22.75 + 6.77}{90} = 0.412$$

$$P_{a_C} = \frac{7.53 + 6.77}{37.05} = 0.386$$

Since each azimuthal fraction will appear with the barrier factor for the mass thickness of partitions in that sector, the following weighted azimuthal fractions are defined:

$$\tilde{A}_{z_A} = A_{z_A}, \quad \tilde{A}_{z_B} = A_{z_B} \, B_i(X_i), \quad \tilde{A}_{z_C} = A_{z_C} \, B_i(2X_i).$$

The functional expressions are written here with the geometry factors as sums over the sectors with the appropriate weighting factors. Note that the contribution from the small wall sections above and below the doors are added in Eqs. (A-17), (A-18), (A-20), and (A-21). The expressions given are for a detector above the window sill and below the top of the window.

$$C_g^{D1} = [\sum^{*}\{[G_d(\omega_\ell',H) - G_d(\omega_\ell,H)]\,\tilde{A}_{z_i}\} + [G_d(\omega_\ell',H) - G_d(\omega_\ell,H)]$$

$$\times A_{z_D}][1-S_w(X_w)]B_e(X_w,H)\;B_f(X_f) \qquad \text{(A-17)}$$

$$C_g^{S1} = [\sum\{[G_s(\omega_\ell') - G_s(\omega_\ell)]\,\tilde{A}_{z_i}\} + [G_s(\omega_\ell') - G_s(\omega_\ell)]\;A_{z_D}]$$

$$\times S_w(X_w)E(e)\;B_e(X_w,H)\;B_f(X_f) \qquad \text{(A-18)}$$

$$C_g^{D2} = [\sum\;\{[G_d(\omega_\ell,H) - P_{a_i}\;G_d(\omega_{a\ell},H)]\;\tilde{A}_{z_i}\}][1-S_w(X_e)]B_e(X_e,H) \qquad \text{(A-19)}$$

$$C_g^{S2} = [\sum\{[G_s(\omega_u) - P_{a_i}G_s(\omega_{au}) - P_{a_i}\;G_s(\omega_{a\ell}) + G_s(\omega_\ell)]\tilde{A}_{z_i}\}$$

$$+ [G_s(\omega_u) - G_s(\omega_{au})]\;A_{z_D}]\;S_w(X_e)\;E(e)\;B_e(X_e,H) \qquad \text{(A-20)}$$

$$C_g^{A2} = [\sum\{[G_a(\omega_u) - P_{a_i}\;G_a(\omega_{au})]\;\tilde{A}_{z_i}\} + [G_a(\omega_u) - G_a(\omega_{au})]A_{z_D}]$$

$$\times [1-S_w(X_e)]\;B_e(X_e,H) \qquad \text{(A-21)}$$

$$C_g^{D3} = B_e(0,H)\;\sum\{G_d(\omega_{a\ell},H)\;P_{a_i}\tilde{A}_{z_i}\} \qquad \text{(A-22)}$$

$$C_g^{A3} = B_e(0,H)\;\sum\{G_a(\omega_{au})\;P_{a_i}\tilde{A}_{z_i}\} \qquad \text{(A-23)}$$

The contributions through the doors are the same as in the non-partitioned cases. For certain combinations of floor height and low detector positions Eqs. (A-17) and (A-18) may be in error because some radiation from the exposed basement wall may reach the detector without intercepting an interior partition. No attempt is made to correct for this.

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* Summation symbol implies summation over i for i equal A, B, and C.

The skyshine contribution through the roof is formulated by differencing the contributions from rectangular areas on the ceiling. Refer to Fig. A-6. The dimensions and solid angle fraction for each rectangular area are tabulated below:

Dimensions	Solid angle fraction
12' x 22'	ω_1
4' x 30'	ω_2
4' x 12'	ω_3
22' x 30'	ω_4
12' x 40'	ω_5
30' x 40'	ω_u

$$C_g^{A4} = \{[A_a(\omega_1) + A_a(\omega_2) - A_a(\omega_3)] + [A_a(\omega_4) + A_a(\omega_5) - A_a(\omega_1) - A_a(\omega_2) + A_a(\omega_3)]\ B_i(X_i) + [A_a(\omega_u) - A_a(\omega_4) - A_a(\omega_5) + A_a(\omega_1)]\ B_i(2X_i)\ \ B_o'(X_r) \qquad \text{(A-24)}$$

6.1.5 Basement Detector Locations

The general basement detector location is shown in Fig. A-7. The aperture fraction for the first story walls, A_p, is defined as the ratio of the window area to the first story wall area. The doors are considered in a separate azimuthal sector as in the first story cases. Refer to Fig. A-8 for this contribution.

$$C_g^{S1} = [G_s(\omega_u') - G_s(\omega_u)]\ S_w(X_w)\ E(e)\ B_e(X_w,3') \qquad \text{(A-25)}$$

$$C_g^{A1} = [G_a(\omega_u') - G_a(\omega_u)][1-S_w(X_w)]\ B_e(X_w,3') \qquad \text{(A-26)}$$

$$C_g^{S2} = \{G_s(\omega''_u) - G_s(\omega'_u) - [G_s(\omega_d) - G_s(\omega'_u)]A_{z_D}\}[1-A_p]S_w(X_e)$$

$$\times\ E(e)\ B_e(X_e,3')\ B'_o(X_f) \tag{A-27}$$

$$= \{G_s(\omega''_u) - A_{z_D} G_s(\omega_d) \quad [1-A_{z_D}]\ G_s(\omega'_u)\}\ [1-A_p]S_w(X_e)$$

$$\times\ E(e)\ B_e(X_e,3')\ B'_o(X_f)$$

$$C_g^{A2} = \{G_a(\omega''_u) - A_{z_D}\ G_a(\omega_d) - [1-A_{z_D}]\ G_a(\omega'_u)\}\ [1-A_p]$$

$$\times\ [1-S_w(X_e)]\ B_e(X_e,3')\ B'_o(X_f) \tag{A-28}$$

$$C_g^{A3} = \{G_a(\omega''_u) - A_{z_D}\ G_a(\omega_{ud}) - [1-A_{z_D}]\ G_a(\omega'_u)\}\ A_p\ B'_o(X_f) \tag{A-29}$$

$$C_g^{A4} = A_a(\omega''_u)\ B'_o(X_o) \tag{A-30}$$

$$C_g^{Sd} = [G_s(\omega_{ud}) - G_s(\omega'_u)]\ S_w(X_d)\ E(e)\ B_e(X_d,3')\ B'_o(X_f)\ A_{z_D} \tag{A-31}$$

$$C_g^{Ad} = [G_a(\omega_{ud}) - G_a(\omega'_u)][1-S_w(X_d)]\ B_e(X_d,3')\ B'_o(X_f)\ A_{z_D} \tag{A-32}$$

For cases where a detector is located in the basement and yet is above grade, shown in Fig. A-9, there is an additional contribution to C_g^{S1} and also a direct radiation component.

$$C_g^{S1} = [G_s(\omega'_u) + G_s(\omega'_\ell)]\ S_w(X_w)\ E(e)\ B_e(X_w,3') \tag{A-33}$$

$$C_g^{D1} = G_d(\omega'_\ell,3')\ [1-S_w(X_w)]\ B_e(X_w,3') \tag{A-34}$$

The effects of interior partitions in the first story on the contributions to a basement detector are neglected. Although the partitions would act as a barrier to some of the radiation reaching a detector in the basement, the fraction of the geometry factor for which this occurs is small and requires much effort to determine. Some initial calculations showed that neglecting the partitions would result in errors of the order of five percent on the conservative side.

6.1.6 Off-center Detector Locations

Off-center detector locations, whether in the basement or upstairs, are treated, in general, by adding the contributions from four fictitious buildings. The fictitious buildings are formed by dividing the plan of the house into four sectors and reflecting each sector into the other three quadrants. Refer to Fig. A-10. The contributions are then determined for each fictitious building, summed, and divided by four. Note that the azimuthal sectors containing the windows and the doors change radically in each fictitious building. If the detector should lie on either the north-south centerline or the east-west centerline of the house, only two fictitious buildings are required.

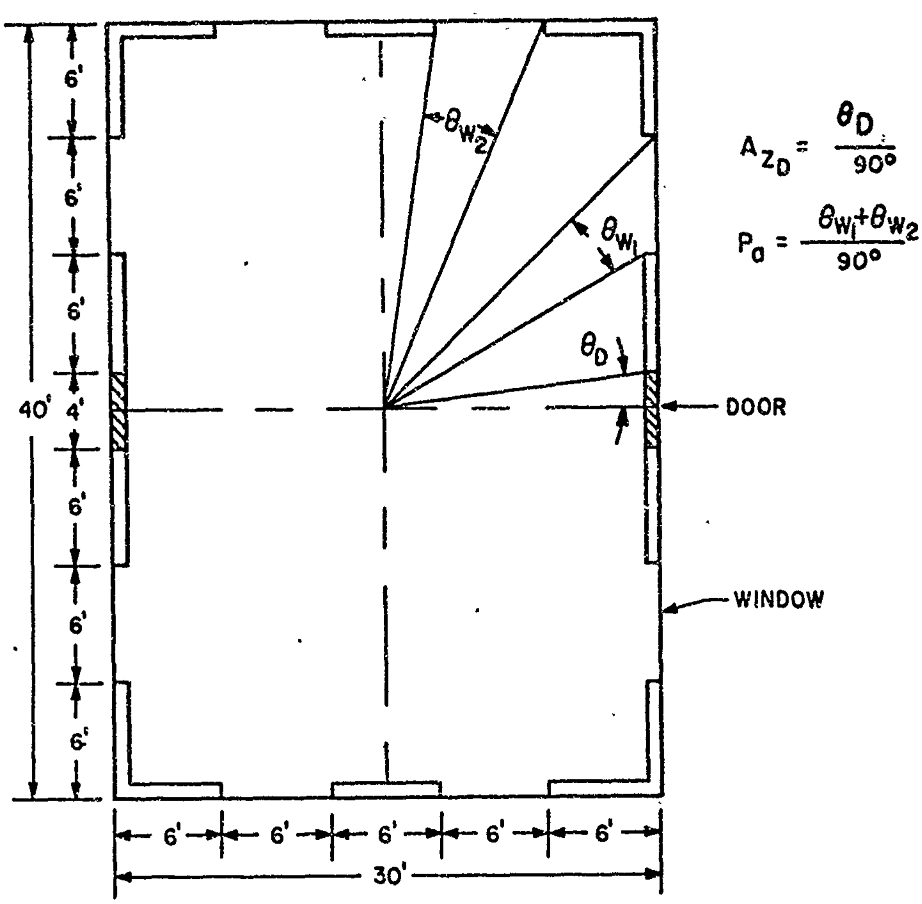


Fig. A-1. Plan of KSU test house showing azimuthal sectors for doors and windows.

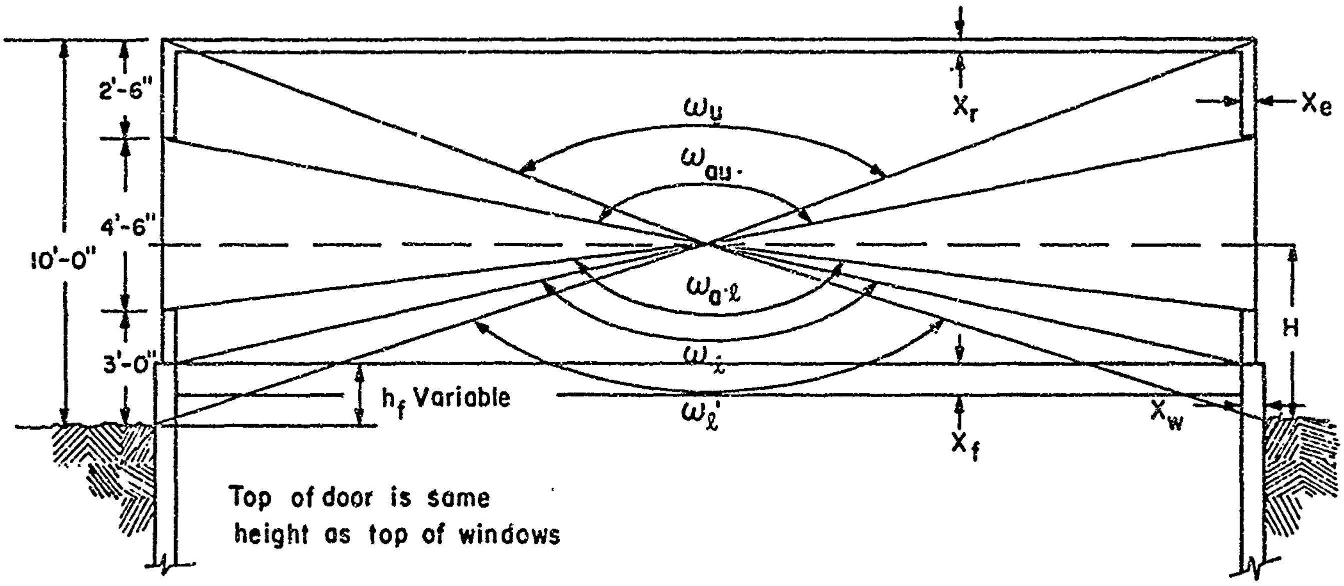


Fig. A-2. Elevation of schematized KSU test house with solid angle fractions for a first-story detector location.

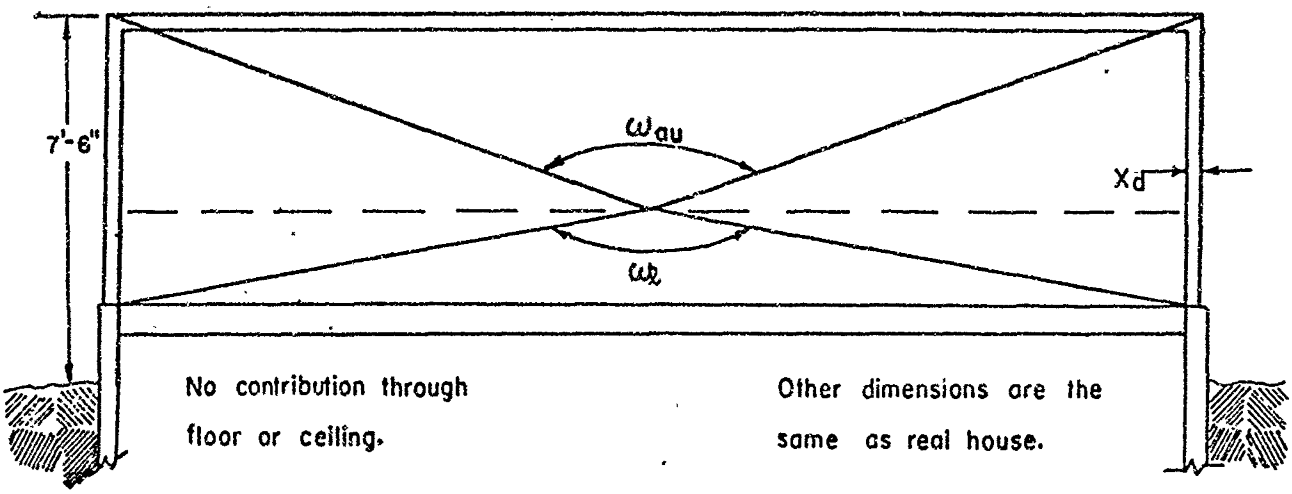


Fig. A-3. Fictitious building for the contribution through the doors to a first story detector location.

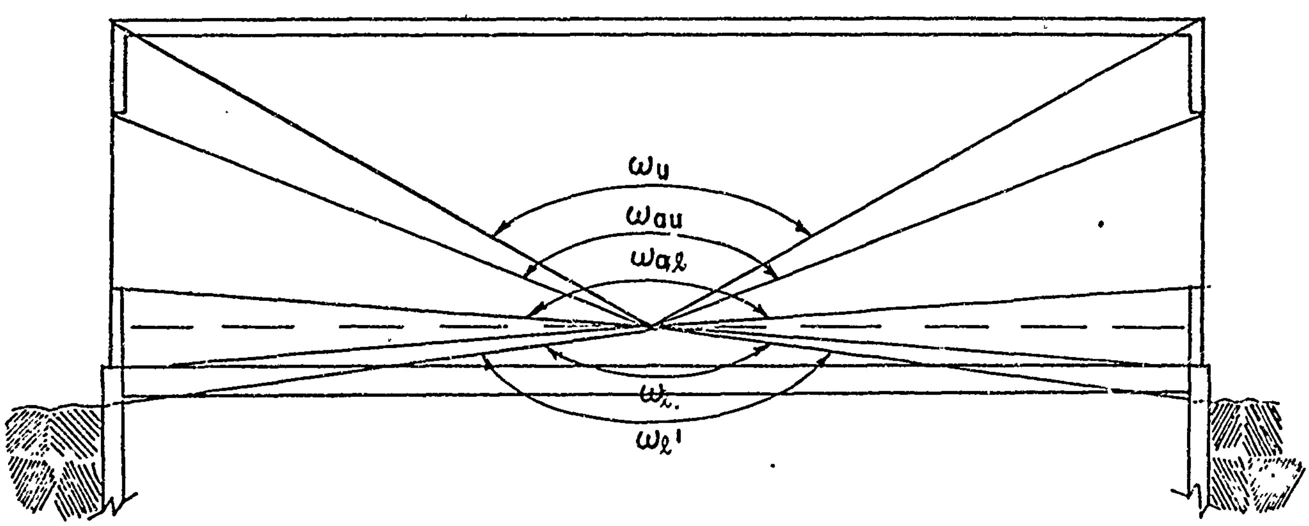


Fig. A-4. Solid angle fractions for a first-story detector below window sill height.

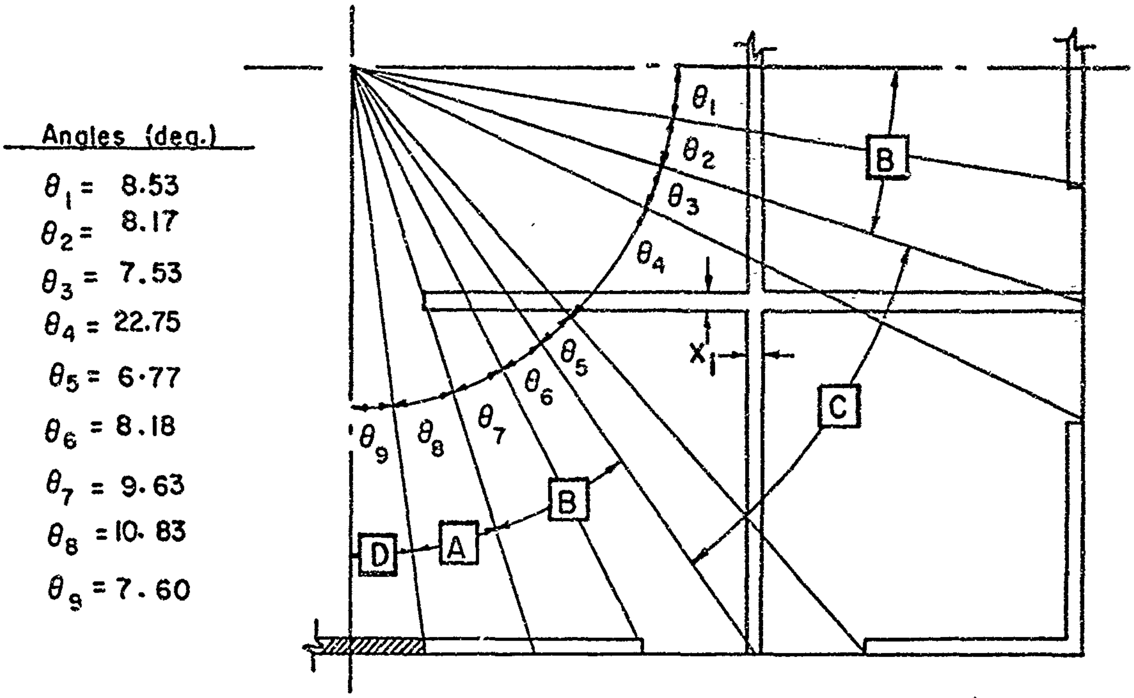
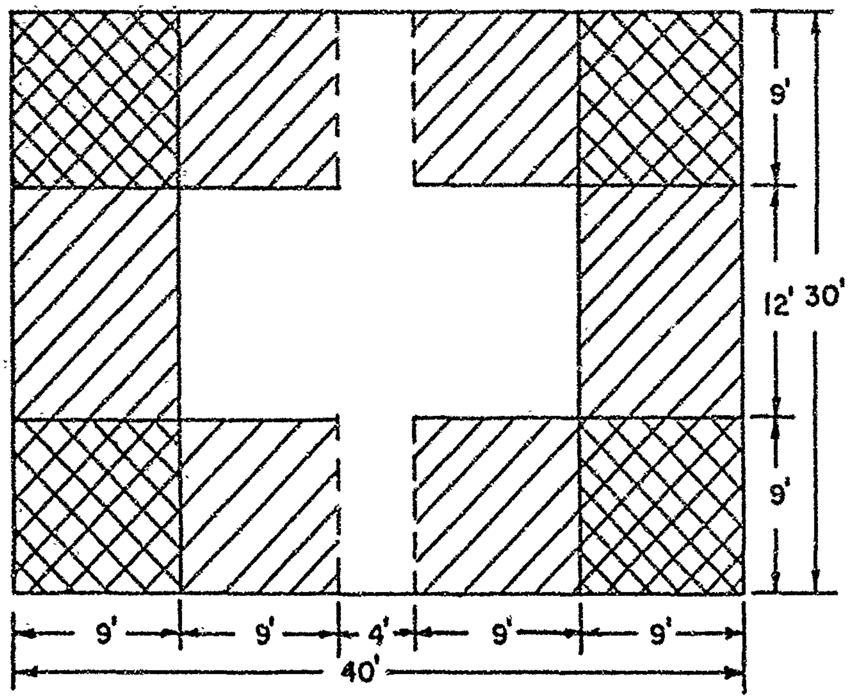


Fig. A-5. Plan of one quarter of KSU test house with interior partitions.



Roof contribution passing through no interior partitions.
Roof contribution passing through one interior partition.
Roof contribution passing through two interior partitions.

Fig. A-6. Rectangular areas on ceiling for roof contribution in partitioned cases.

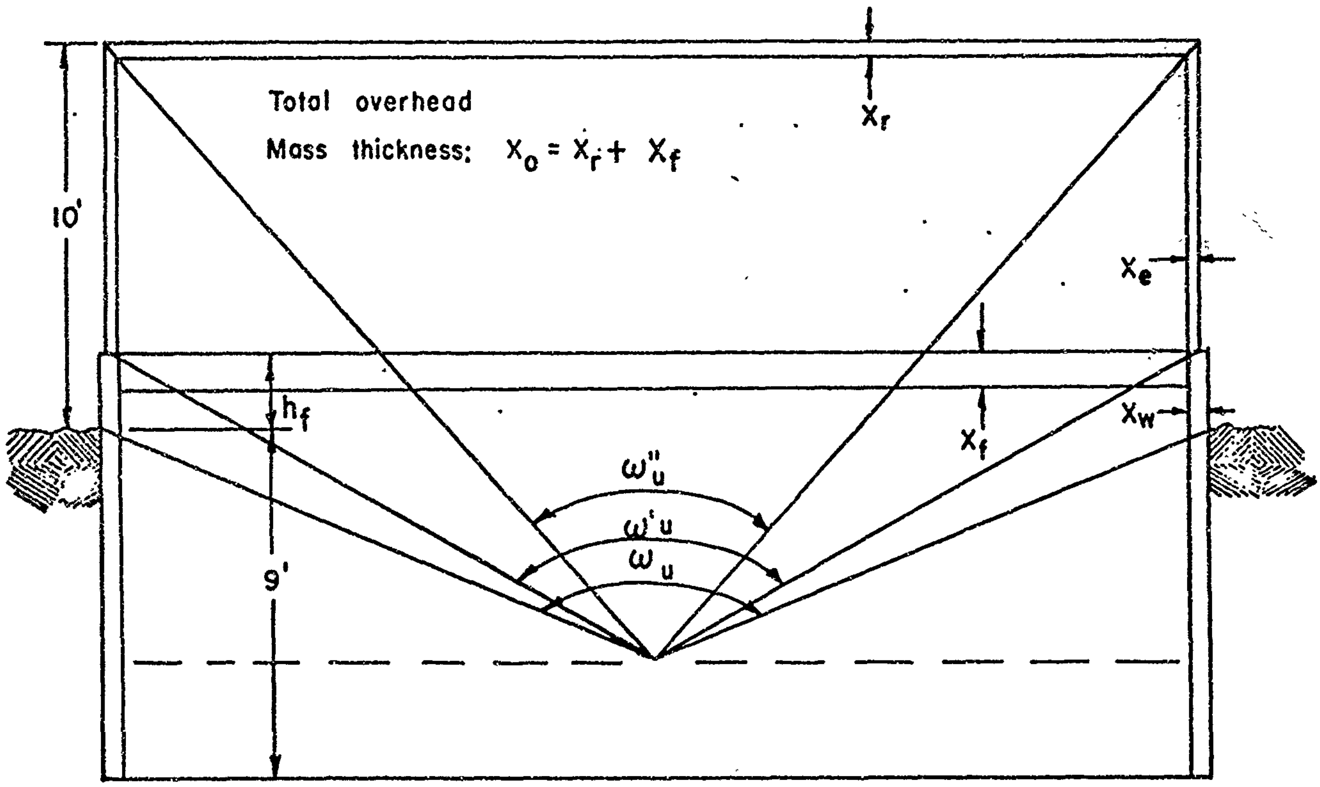


Fig. A-7. Elevation of schematized KSU test house showing solid angle fractions for a basement detector location.

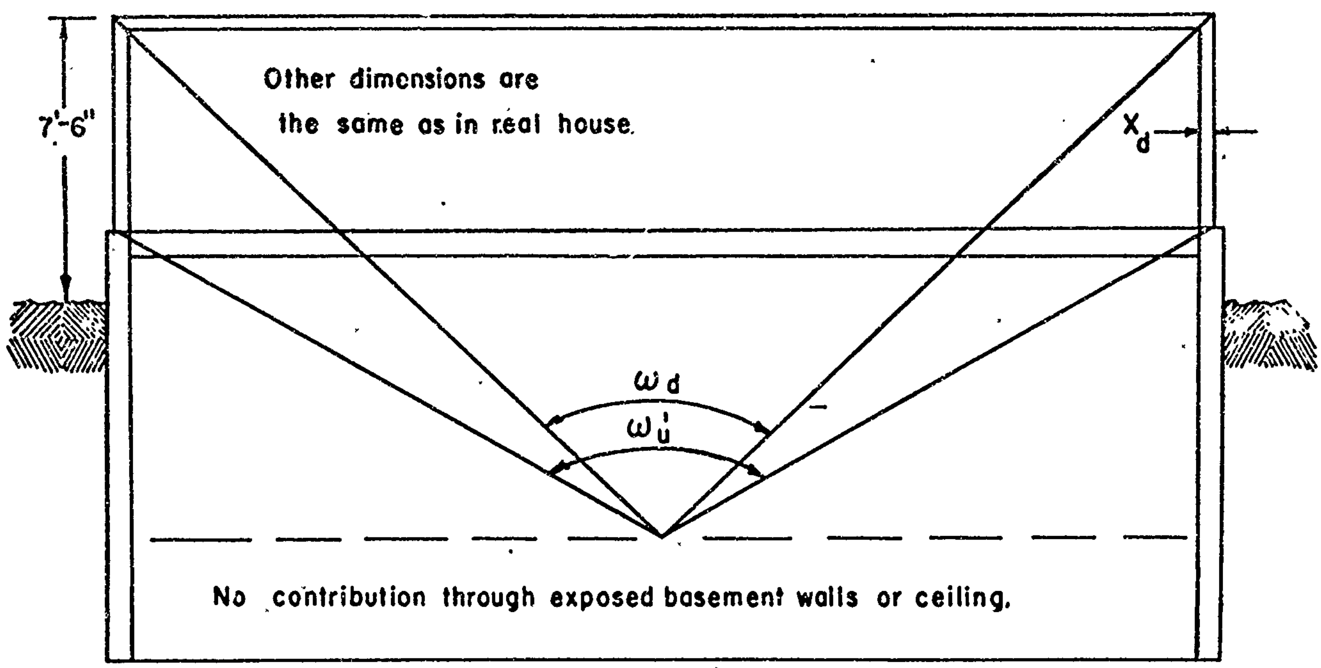


Fig. A-8. Fictitious building for the contribution through the doors to a basement detector location.

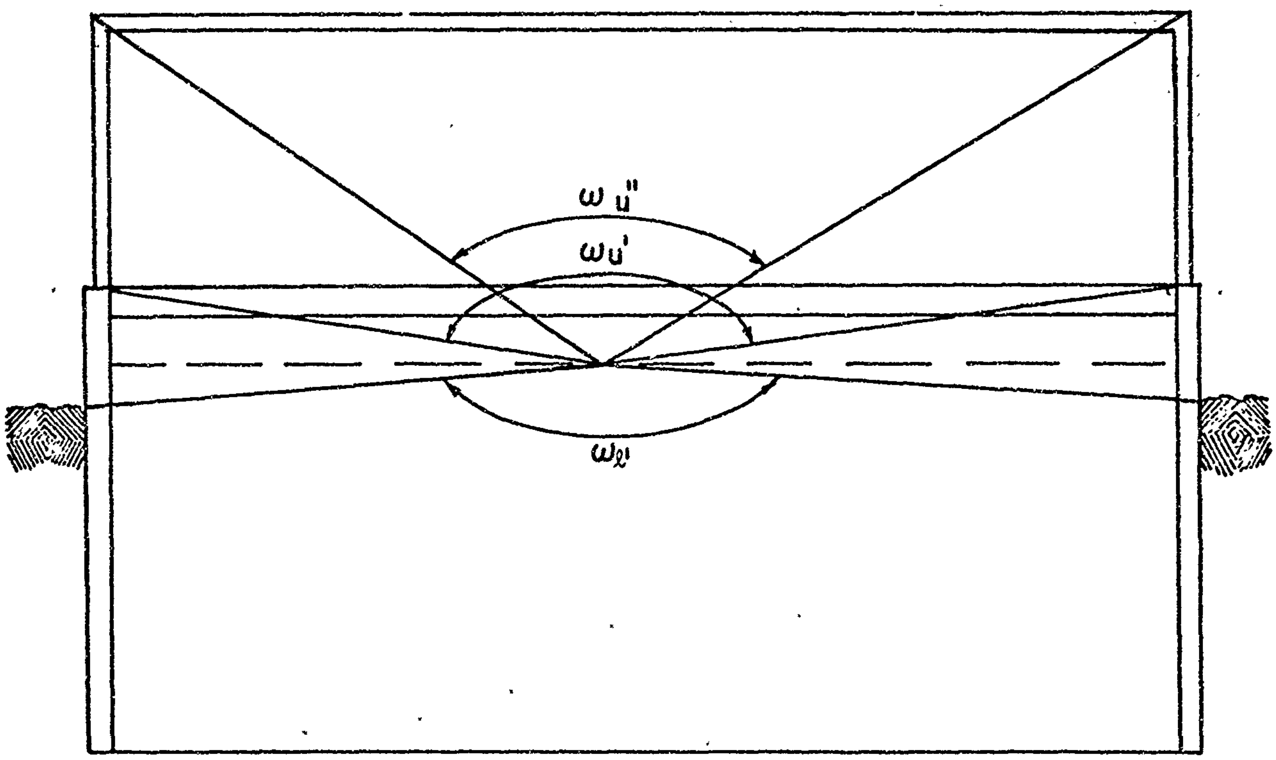


Fig. A-9. Solid angle fractions for a basement detector location above grade.

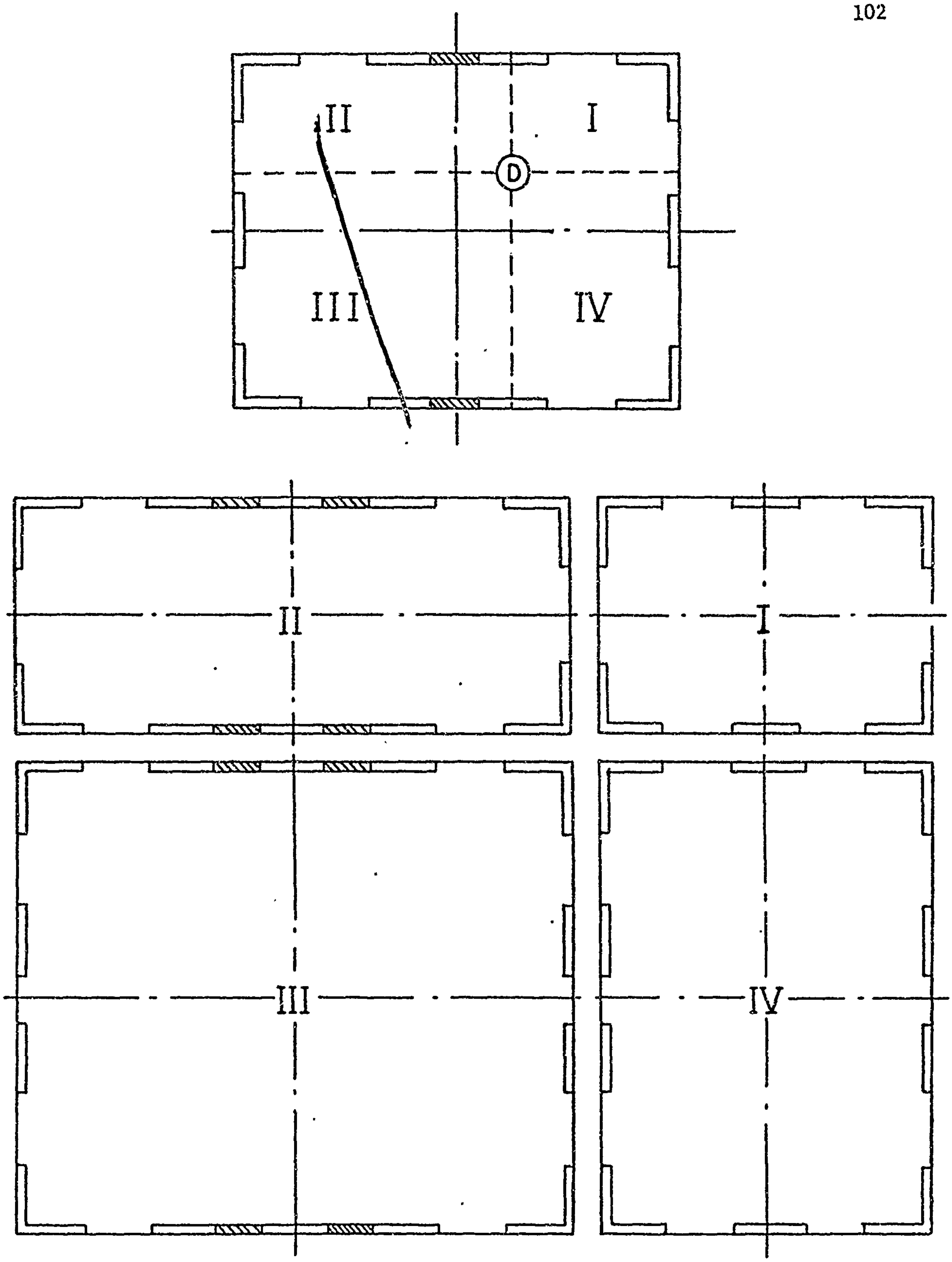


Fig. A-10. Fictitious buildings required for a typical off-center detector location.

6.2 Appendix B, Preparation of EM Charts for ^{60}Co Radiation

6.2.1 Introduction

The purpose of this section is to describe the mechanics used to convert the NBS-42 data (1) to the tabular data for the EM charts used in the computer code ENGMAN. The charts were constructed only for the ranges of the parameters required for the KSUNESF test house. No physical interpretation of the functions involved is given here nor is any justification given for their use.

6.2.2 General Methods

Spencer (1) has performed basic radiation transport calculations for three gamma-ray sources, 1.12 hour fission products, ^{60}Co, and ^{137}Cs. The data from the fission product spectrum were used to construct the EM charts as outlined in (2[Vol. II] and 3). Here the identical procedures are used to construct the charts from the ^{60}Co data.

The following functions, which were calculated by Spencer and plotted in NBS-42, were used: $L(X)$, $S(d)$, $S'(X)$, $P^{(O)}(X)$, $P^{(S)}(X)$, $W(X,d)$, $L_a(X,\omega)$, $S_a(d,\omega)$. Values were read as accurately as possible from these curves for the ranges of interest and are listed in Tables B-1 through B-3. The appropriate calculations (shown later) were carried out on these numbers to convert them to EM functions.

The data were then plotted and smooth curves drawn through the points to represent the EM functions, Figures B-1 through B-5. The tabular data were then read from these curves and are recorded in Tables B-4 through B-7. It was hoped that this graphical smoothing process would diminish any errors arising from the reading of the NBS-42 curves.

It is noted that the parameters X and d both represent mass thickness. The units of X are pounds per square foot (psf), while the units of d are feet of air. They are used interchangeably below, the relation between the two being: 1.0 psf = 13.3 feet of air.

6.2.3 Barrier Factors

Two EM functions are identical to NBS-42 functions:

$$B_f(X) = L(X) \qquad \text{(B-1)}$$

and

$$B_o'(X) = S'(X). \tag{B-2}$$

The scattered fraction is defined here as the ratio of scattered to total dose rates from a point isotropic source:

$$S_w(X) = \frac{P^{(S)}(X)}{P^{(0)}(X) + P^{(S)}(X)} . \tag{B-3}$$

The wall barrier factor is defined by the approximate relationship

$$B_e(X,H) \simeq 2W(X,d), \tag{B-4}$$

where the EM variable H is equal to d. The NBS-42 function W(X,d) is for a detector imbedded thickness X in a semi-infinite wall. For low mass thicknesses, there is a significant contribution to the detector response from radiation which has been back-scattered in the wall material behind the detector. This is evidenced by the fact that $2 \cdot W(0,3') = 1.1$. To correct for this effect in the function $B_e(X,H)$, the value for X = 0 and H = 3' was set equal to 1.0 and the curve was lowered slightly out to X ≃ 50 psf. Proportional corrections were made in the curves for H = 6' and H = 15'.

The barrier factor for interior partitions is set equal to the wall barrier factor at H = 3':

$$B_i(X) = B_e(X,3'). \tag{B-5}$$

6.3.4 Geometry Factors

The following definitions of the NBS-42 functions are required to formulate the EM functions:

$$L(X) = \int_{-1}^{1} d(\cos\theta)\ \ell(X,\cos\theta) \tag{B-6}$$

$$L_a(X,\omega) = \frac{1}{L(X)} \int_{1-\omega}^{1} d(\cos\theta)\ \ell(X,\cos\theta) \tag{B-7}$$

$$S(d) = \int_{-1}^{0} d(\cos\theta)\ \ell(d,\cos\theta) \tag{B-8}$$

$$S_a(d,\omega) = \frac{1}{S(d)} \int_{-1}^{-1+\omega} d(\cos\theta)\ \ell(d,\cos\theta). \tag{B-9}$$

In addition, the following values are needed:

$L(.2256) = 1.0$

$L(1.0) = 0.74$

$S(0) = 0.088$

$S(3') = 0.084$

$S(13.3') = 0.0755$

3' (of air) = 0.2256 psf.

The EM geometry factors are now expressed in terms of these functions:

$$G_d(\omega,H) = \frac{\int_{0}^{1-\omega} d(\cos\theta)\ \ell(d,\cos\theta)}{\int_{-1}^{1} d(\cos\theta)\ \ell(d,\cos\theta)} \tag{B-10}$$

$$= L_a(d,1) - L_a(d,\omega)$$

$$G_s(\omega) = \int_{-1+\omega}^{0} d(\cos\theta)\ \ \ell(3',\cos\theta) \tag{B-11}$$

$$= 0.5\ [1-S_a(3',\omega)]$$

$$G_s(0) = 0.5$$

$$G_a(\omega) = S(3')[1-S_a(3',\omega][1 + 0.5\ S_a(3',\omega)] \tag{B-12}$$

$$A_a(\omega) = \int_{1}^{-1+\omega} d(\cos\theta)\ \ell(0,\cos\theta) \tag{B-13}$$

$$= S(0)\ S_a(0,\omega)\ .$$

In the construction of the original EM charts for the fission product spectrum, the functions $G_d(\omega,H)$ and $G_a(\omega)$ were arbitrarily normalized such that $G_d(0,3') = 0.9$ and $G_a(0) = 0.1$. No such round-off has been carried out here.

In the input tables for ENGMAN it was desired to have values for $B_e(X,H)$ and $G_d(\omega,H)$ for the same set of heights. Since $L_a(X,\omega)$ is only plotted for $X = 0.2256$ ($H = 3'$) and $X = 1$ ($H = 13.3'$), the functions $G_d(\omega,3')$ and $G_d(\omega,13.3')$ were constructed and linear interpolation was used to obtain values for the heights 6' and 15'.

The function $A_a(\omega)$ requires values of $S_a(d,\omega)$ for $d = 0$, whereas $S_a(3',\omega)$ is the lowest curve in NBS-42. However, the shape of this curve should be quite insensitive to such a small change in height.

TABLE B-1. Data taken from NBS-42 curves for the functions L(X), S'(X), $P^{(0)}(X)$, and $P^{(S)}(X)$ for ^{60}Co radiation.

X(psf)	L(X)	S'(X)	$P^{(0)}(X)$	$P^{(S)}(X)$
0	1.0*	1.0	0.360	0.0
5	0.43	0.54	0.320	0.040
10	0.305	0.347	0.277	0.069
15	0.237	0.245	0.240	0.090
20	0.193	0.180	0.210	0.103
25	0.160	0.139	0.181	0.111
30	0.131	0.109	0.160	0.120
40	0.095	0.070	0.120	0.126
50	0.069	0.046	0.091	0.121
60	0.051	0.030	0.070	0.113
70	0.038	0.0200	0.052	0.103
80	0.0286	0.0130	0.0400	0.092
90	0.0220	0.0086	0.0300	0.081
100	0.0164	0.0057	0.0230	0.069

*This value is actually for X = 0.2256

TABLE B-2. Data taken from NBS-42 curves for the function W(X,d) for ^{60}Co radiation.

X(psf)	W(X,d) d = 3'	6'	15'
0	0.55	0.47	0.39
5	0.47	0.41	0.33
10	0.40	0.360	0.285
20	0.31	0.272	0.215
30	0.238	0.207	0.165
40	0.188	0.161	0.178
50	0.147	0.125	0.098
60	0.116	0.099	0.078
70	0.091	0.078	0.061
80	0.072	0.061	0.048
90	0.050	0.042	0.033
100	0.044	0.038	0.029

TABLE B-3. Data taken from NBS-42 curves for the functions $L_a(X,\omega)$ and $S_a(X,\omega)$ for ^{60}Co radiation.

ω	$L_a(.2256,\omega)$	$L_a(1.0,\omega)$	$S_a(3,\omega)$
0.0	0.0	0.0	0.0
0.05	0.0097*	0.0128	0.0148
0.10	0.0204	0.0280	0.0321
0.15	0.0314	0.0492	0.0538
0.20	0.0460	0.0615	0.0775
0.30	0.0745	0.099	0.126
0.40	0.108	0.144	0.179
0.50	0.146	0.198	0.250
0.60	0.191	0.264	0.331
0.70	0.253	0.352	0.428
0.80	0.344	0.470	0.56
0.85	0.403	0.550	0.67
0.90	0.49	0.64	0.73
0.95	0.61	0.76	0.85
1.00	0.916	0.898	0.00

* Extrapolated value

TABLE B-4. Tabular ^{60}Co data for Engineering Manual functions $B_o'(X)$, $B_f(X)$, $B_i(X)$, and $S_w(X)$.

X(psf)	$B_o'(X)$	$B_f(X)$	$B_i(X)$	$S_w(X)$
0	1.0	1.0	1.0	0.0
5	0.54	0.43	0.870	0.110
10	0.350	0.305	0.757	0.199
15	0.245	0.240	0.662	0.272
20	0.180	0.193	0.585	0.330
25	0.139	0.160	0.516	0.382
30	0.109	0.131	0.458	0.429
40	0.070	0.095	0.360	0.505
50	0.0457	0.069	0.283	0.568
60	0.0298	0.051	0.224	0.620
70	0.0197	0.0382	0.179	0.665
80	0.0130	0.0288	0.141	0.702
90	0.0086	0.0218	0.112	0.731
95	0.0070	0.0188	0.100	0.741
100	0.0058	0.0164	0.089	0.749

TABLE B-5. Tabular ^{60}Co data for Engineering Manual function $B_e(X,H)$.

	$B_e(X,H)$		
X(psf)	H=3'	H=6'	H=15'
0	1.00	0.870	0.708
5	0.870	0.762	0.613
10	0.757	0.670	0.532
15	0.662	0.590	0.462
20	0.585	0.520	0.405
25	0.516	0.460	0.358
30	0.458	0.406	0.315
40	0.360	0.318	0.245
50	0.283	0.250	0.193
60	0.224	0.197	0.152
70	0.179	0.155	0.120
80	0.141	0.122	0.0945
90	0.112	0.0962	0.0743
95	0.0995	0.0851	0.0660
100	0.0885	0.0758	0.0585

TABLE B-6. Tabular ^{60}Co data for Engineering Manual functions $G_s(\omega)$, $G_a(\omega)$, $A_a(\omega)$, and $G_d(\omega,3')$.

ω	$G_s(\omega)$	$G_a(\omega)$	$A_a(\omega)$	$G_d(\omega,3')$
0.0	0.500	0.0840	0.0	0.916
0.05	0.492	0.0834	0.0012	0.907
0.10	0.483	0.0826	0.0027	0.896
0.15	0.473	0.0816	0.0045	0.884
0.20	0.462	0.0806	0.0065	0.870
0.30	0.438	0.0782	0.0110	0.842
0.40	0.410	0.0751	0.0160	0.808
0.50	0.375	0.0709	0.0220	0.770
0.60	0.335	0.0655	0.0291	0.725
0.70	0.286	0.0583	0.0377	0.663
0.80	0.220	0.0476	0.0485	0.572
0.85	0.182	0.0409	0.0554	0.513
0.90	0.134	0.0310	0.0642	0.426
0.92	0.113	0.0263	0.0682	0.389
0.94	0.090	0.0213	0.0723	0.336
0.96	0.064	0.0156	0.0770	0.270
0.98	0.035	0.0086	0.0819	0.175
1.00	0.0	0.0	0.0880	0.0

TABLE B-7. Tabular ^{60}Co data for Engineering Manual function $G_d(\omega,H)$.

	$G_d(\omega,H)$		
ω	H=3'	H=6'	H=15'
0.0	0.916	0.911	0.895
0.05	0.907	0.901	0.881
0.10	0.896	0.888	0.886
0.15	0.884	0.875	0.849
0.20	0.870	0.860	0.832
0.30	0.842	0.829	0.792
0.40	0.808	0.792	0.745
0.50	0.770	0.750	0.688
0.60	0.725	0.698	0.619
0.70	0.663	0.629	0.527
0.80	0.572	0.530	0.404
0.85	0.513	0.465	0.321
0.90	0.426	0.377	0.230
0.92	0.389	0.339	0.187
0.94	0.336	0.288	0.143
0.96	0.270	0.227	0.096
0.98	0.175	0.142	0.045
1.00	0.0	0.0	0.0

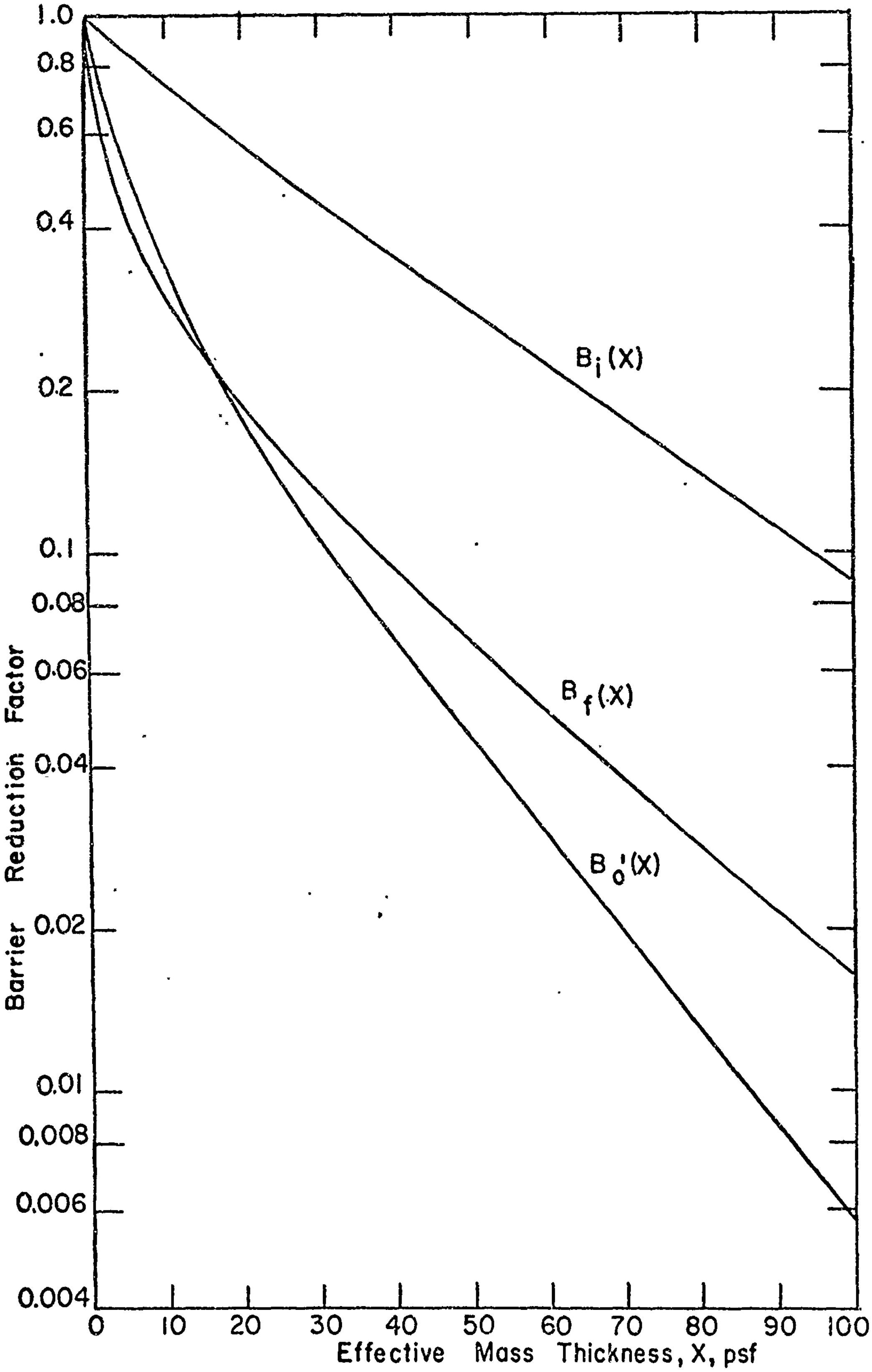


Fig. B-1. The Engineering Manual functions $B'_o(X)$, $B_f(X)$ and $B_i(X)$ for ^{60}Co radiation.

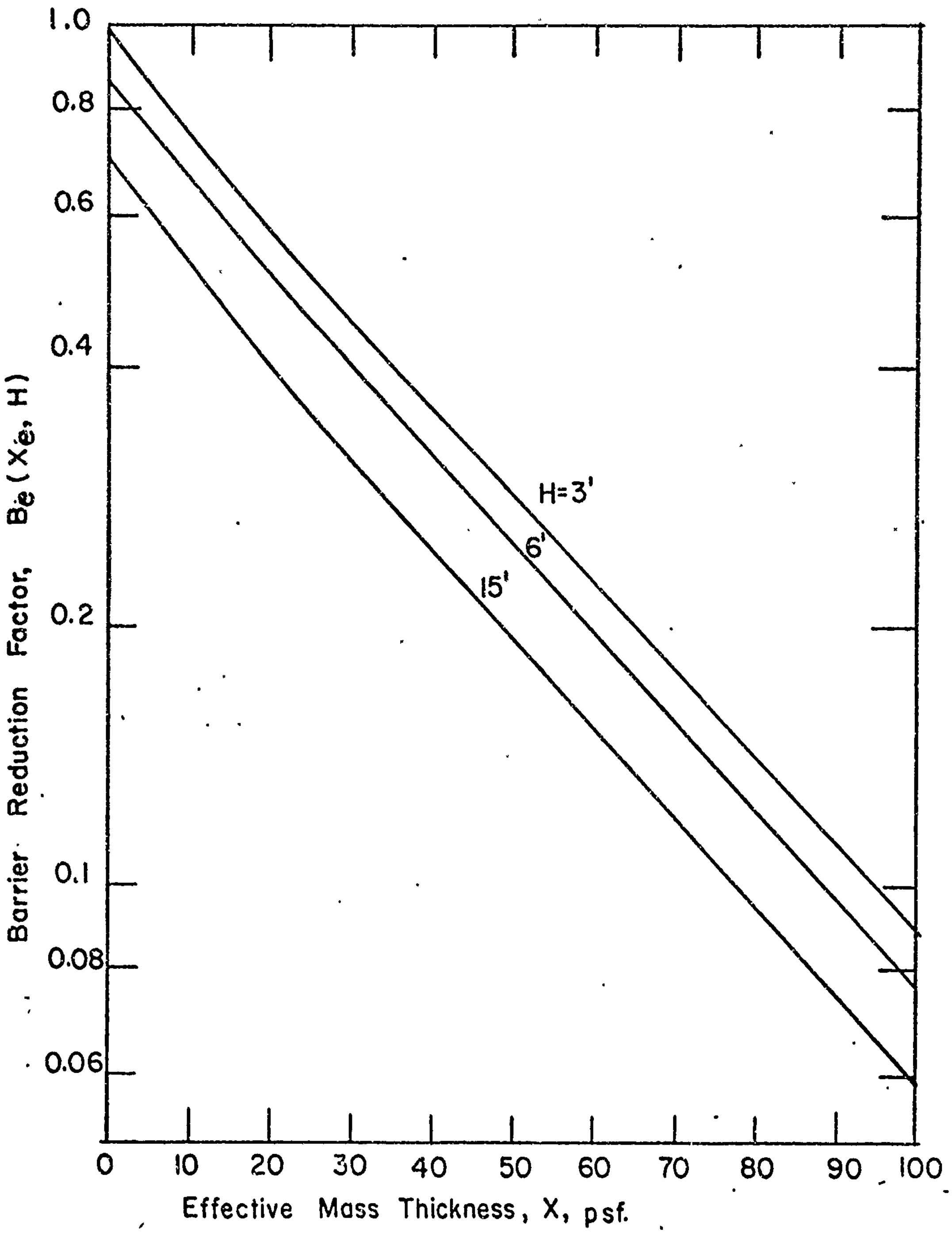


Fig. B-2. The Engineering Manual Function B_e (X_e, H) for ^{60}Co radiation.

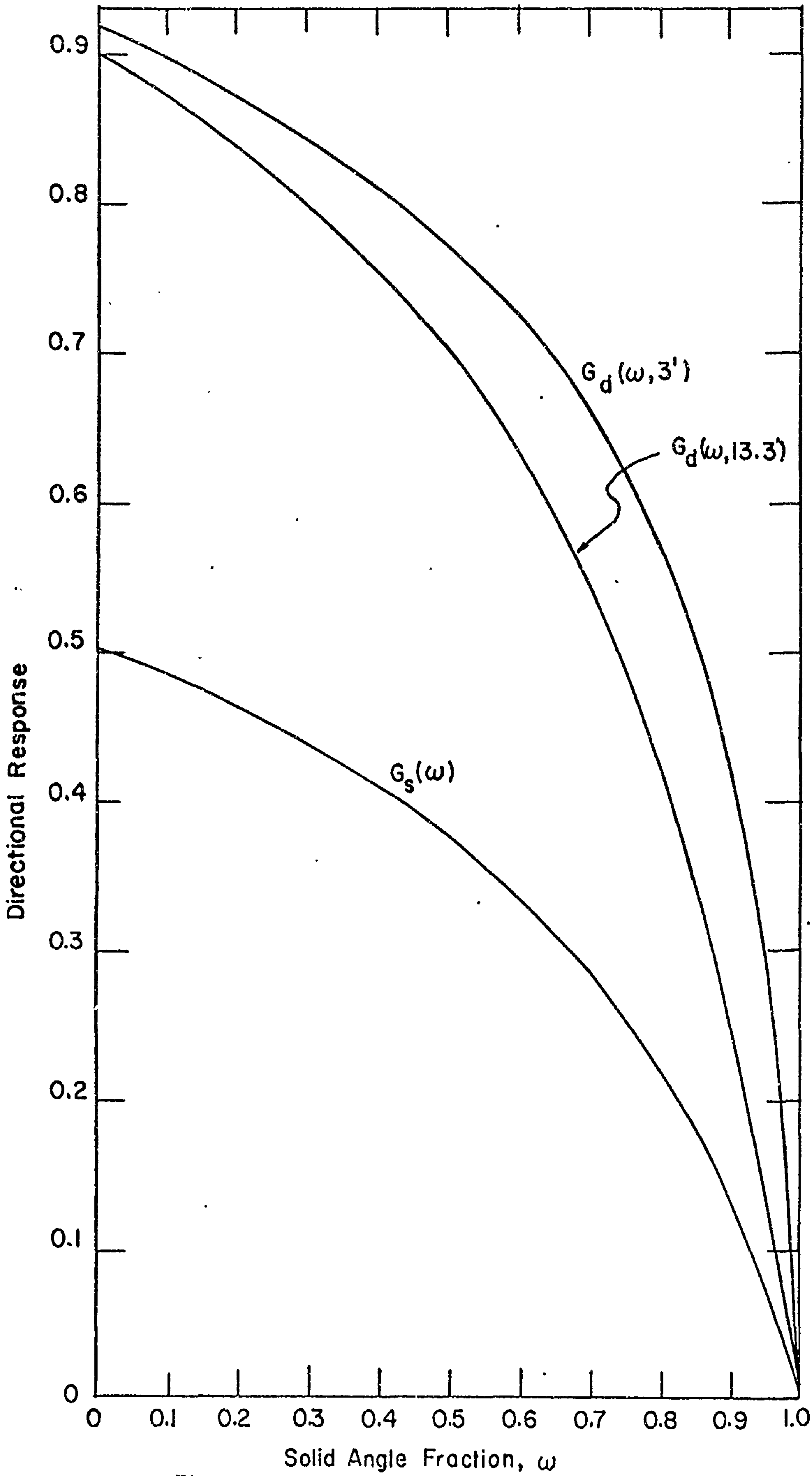


Fig. B-3. The Engineering Manual functions G_s (ω) and G_d (ω,H) for ^{60}Co radiation

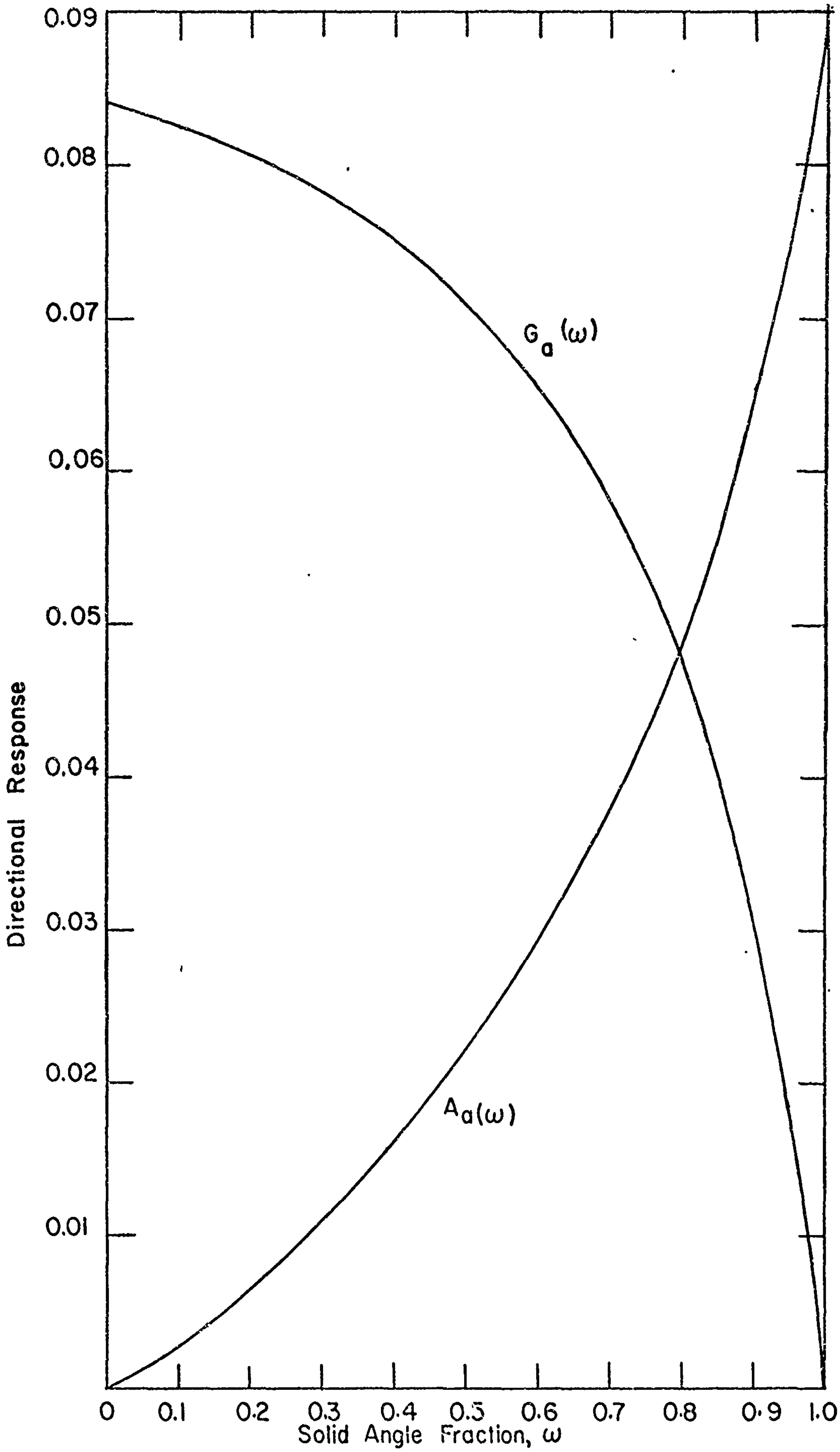


Fig. B-4. The Engineering Manual functions $G_a(\omega)$ and $A_a(\omega)$ for ^{60}Co radiation.

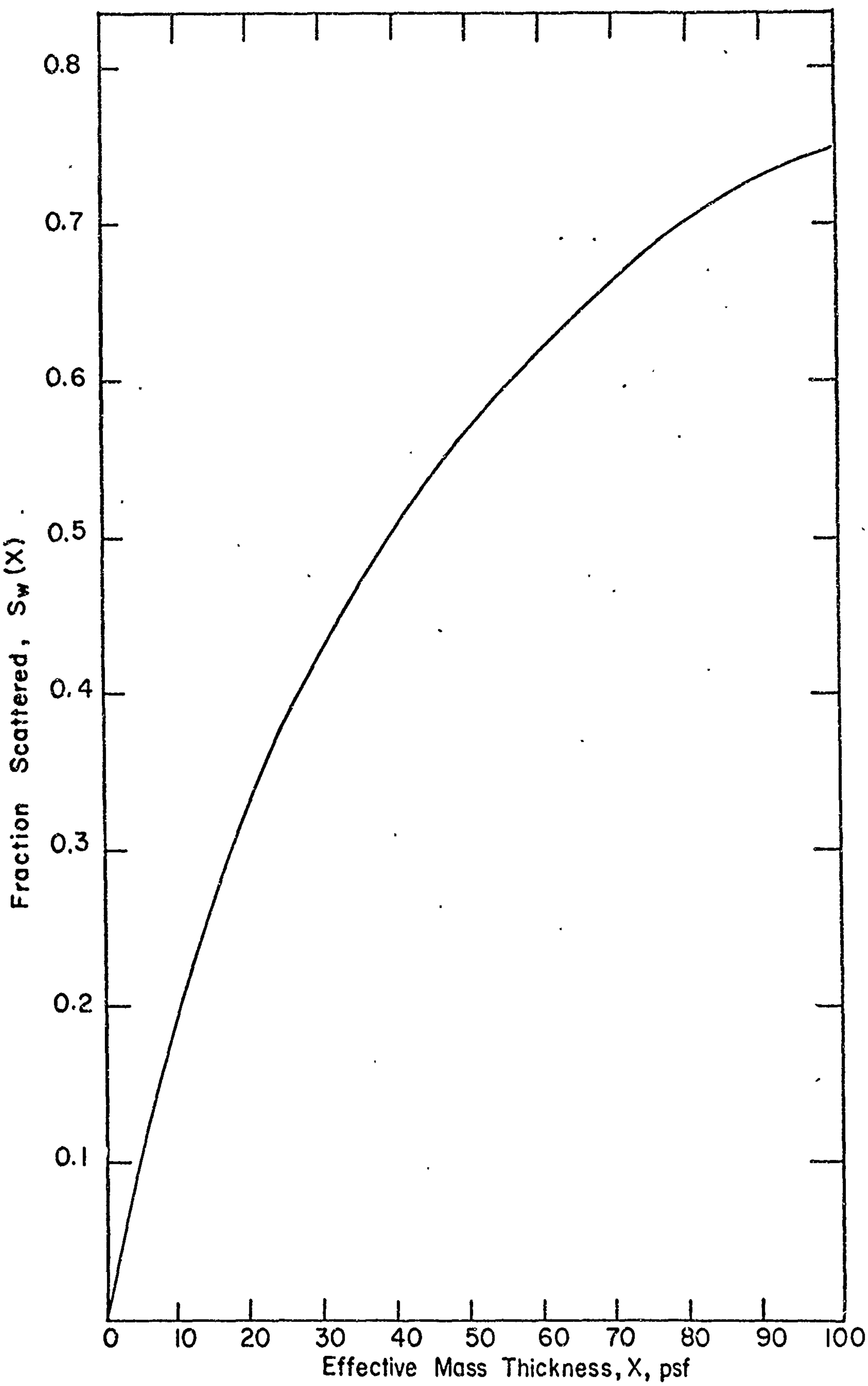


Fig. B-5. The Engineering Manual function $S_w(X)$ for ^{60}Co radiation.

6.3 Appendix C, Calibration of the Dosimeters

This appendix describes briefly the experiment in which both types of dosimeters were calibrated. The equations used for determining the regression lines and associated statistics are cited but no derivation is given.

6.3.1 Experimental Procedure

The calibration experiment was conducted inside the instrument-storage building (a Butler-type building) at the KSUNESF. Two dosimeter racks were constructed of 1/2" plywood cut in the shape of a circular arc of radius 7 ft. Holes of 0.4" diameter were drilled in the racks with a spacing of four inches. The racks were suspended from the ceiling braces so that the centers of the racks were on opposite ends of the diameter of a circle of seven-feet radius. Each rack could accommodate up to twenty dosimeters of either type.

A point ^{60}Co source of nominally 0.3 Ci was used for the irradiations. The source was manipulated by means of a "gamma-ray projector." The projector consisted of a portable lead storage container with a flexible cable on one end of which the source was mounted. The cable was drawn through a flexible housing by a cranking mechanism which allowed the experimenter to stand some twenty-five feet from the storage container. When the source was fully exposed, it was located at the opposite end of the cable housing which also extended twenty-five feet from the storage container. By a system of lights, the experimenter could tell whether the source was fully exposed, in an intermediate position, or stored.

When the dosimeters were in the racks and the tip of the source cable was positioned midway between the racks, the source-to-detector distance was seven feet with a maximum tolerance of $\pm$ 1/2". In this configuration the dosimeters received an approximate exposure-rate of 1 mR/min.

The exposure time was measured from the moment the source reached the fully exposed position to the moment the source had begun to be retracted. About two-thirds of the cable housing between the storage container and the exposed tip was shielded with lead bricks. However the dosimeters were still exposed to unwanted radiation as the source traveled from the storage container to the tip. This unwanted exposure was determined by measurement to be about 0.1/mR. Corrections were made for this in the data analysis.

The 10-mR chambers were charged to full voltage with the Tech/ops charger-reader and placed in the dosimeter rack. After irradiation they were recharged to full voltage while the meter on the charger-reader indicated a value proportional to the amount of charge neutralized by the ionizing radiation. The readings were recorded in microamperes. The exposure times varied from two to eight minutes.

The TL-12 dosimeters had to be zeroed by the read-out process before use since they were observed to accumulate a "background" dose of about 1 mR per day. There were 66 of these dosimeters and, as will be pointed out below, a separate regression line had to be determined for each. No less than ten exposures were taken for each dosimeter in the initial calibration. The exposure time varied from five to thirty-two minutes. The height of the glow curve was recorded for each reading in units of the scale divisions on the strip charts.

Since the response of the air-equivalent chambers is proportional to the density of the surrounding air medium, the chamber readings were normalized to the air density at 22° C and 760 mm of Hg. This was accomplished by multiplying the readings by an air-density correction factor β, given by

$$\beta = \frac{760(273 + T)}{295\ P} \qquad \text{(C-1)}$$

where T is the temperature in degrees Celsius and P is the pressure in millimeters of Hg.

6.3.2 Calculated Exposure Rate

The calculated exposure rate θ was determined from the following formula:

$$\theta = \frac{KS_c Be^{-\mu x}\, e^{-\lambda d}}{4\ \pi\ x^2}\ ; \qquad \text{(C-2)}$$

where
- K = flux-to-dose conversion factor [mR·cm^2 sec/min],
- S_c = calibration source strength at the time of the source calibration [photons/sec],
- B = dose build-up factor for air-scattering and floor reflection,
- μ = total linear attenuation coefficient for 1.25 MeV photons in air [cm^{-1}],

d = time between the source calibration and the dosimeter calibration [days],

x = source to detector distance [cm],

λ = decay constant for ^{60}Co [days^{-1}].

One roentgen corresponds to an absorbed dose of 87.7 erg/g in air (19). The absorbed dose rate from a unit flux of ^{60}Co photons is given by

$$\text{absorbed dose rate} = E_\gamma \hat{\mu}_d (E_\gamma)\phi_\gamma = 5.32\text{x}10^{-8} \ [\text{erg/g} \cdot \text{sec}]$$

where $E_\gamma = 1.25 \text{ MeV} = 2.00\text{x}10^{-6}\text{erg}$,

$\hat{\mu}_d(E_\gamma) = 0.0266 \text{ cm}^2/\text{g}$, the linear attenuation coefficient for energy absorption of 1.25 MeV photons in air, divided by the density of air (20),

φ_γ = unit flux of 1.25 MeV photons [photon/sec$\cdot$cm^2].

This absorbed dose rate would correspond to an exposure rate (for a unit flux) given by,

$$\begin{aligned}\text{exposure rate} &= (5.32 \times 10^{-8} \text{ erg/g}\cdot\text{sec}) \ (1\text{R}/87.7 \text{ erg/g}) \ (60\text{sec/min}) \\ &= 3.65 \times 10^{-8} \text{ R/min}.\end{aligned}$$

The conversion factor K becomes

$$K = 3.65 \times 10^{-5} \text{ mR} \cdot \text{cm}^2 \cdot \text{sec/min},$$

which gives the exposure rate when multiplied by the flux in photons/ cm$^2\cdot$sec.

The calibration source was calibrated in a previous experiment which yielded the following source strength as of August 10, 1965;

$$\begin{aligned}S_c &= 0.246 \pm 0.007 \text{ Ci} \\ &= 1.82 \times 10^{10} \text{ photons/sec (21)}.\end{aligned}$$

There are two other contributions to the radiation incident on the detector besides the unscattered radiation. These are the radiation due to air scattering

and the radiation which is reflected from the concrete floor. The build-up factor must therefore have the form

$$B = 1 + \frac{D_{\text{air scat.}}}{D_{\text{unscat.}}} + \frac{D_{\text{floor ref.}}}{D_{\text{unscat.}}} .$$

The first ratio is found from an expression for the build-up factor for a point source in an infinite air medium (22).

$$\frac{D_{\text{air scat.}}}{D_{\text{unscat.}}} = 0.92\ r\ e^{0.0632\ r} = 0.0135;$$

where $r = \mu x = \hat{\mu}\rho x = 0.0146$,
$\hat{\mu} = 0.0573\ \text{cm}^2/\text{g}$
$\rho = 0.001195\ \text{g/cm}^3$ (This is an average value for the atomospheric conditions observed during the experiments),
$x = 213.36$ cm = 7ft.

The second ratio was taken from a report in which are tabulated the values of the ratios of the reflected dose rates for a source and detector in vacuum adjacent to a semi-infinite concrete slab (23). The values are tabulated as a function of the source height and photon energy. The value for a source and detector six feet above a concrete slab and for 1.25MeV photons was taken to be 0.018. Hence,

$$B = (1 + 0.0135 + 0.018) = 1.032.$$

The attenuation in air is given by

$$e^{-\mu x} = e^{-\hat{\mu}\rho x} = 0.9855.$$

The product $Be^{-\mu x}$ has the value 1.017, and varied by less than 0.001 for any atmospheric changes observed during the experiments.

The decay constant for ^{60}Co in day^{-1} is given by

$$\lambda = \frac{\ln 2}{(5.24)(365)} = 0.0003624 \text{ day}^{-1}$$

When all these definitions are substituted into Eq. (C-2), the result is

$$\theta = \frac{(3.65\times10^{-5})(1.82\times10^{10})(1.017)\, e^{-0.0003624d}}{4\,\pi\,(213.36)^2} \tag{C-3}$$

$$= 1.181\, e^{-0.0003624d} \quad \text{mR/min;}$$

where the reference date for d is August 10, 1965.

6.3.3 Regression Analysis

It was assumed that the dosimeter response η is related to the true exposure ξ by the equation $\eta=\beta\xi$ and that the observations y_i are distributed normally about η. It was also assumed that there was no error in the calculated exposures. This was not exactly true since there was about a 0.5 percent uncertainty in the source-to-detector distance and some uncertainty in the exposure time (about one percent for two minutes and proportionately less for longer times.) However, these errors are considered as an additional spread in the observations. Although there was a 3.0 percent error in the calibration source strength S_c, this was a constant, rather than a random, error. It was treated as a systematic error, and its propagation is discussed in Appendix D.

For a given dosimeter, a set of k dosimeter readings; $y_1, y_2, \ldots y_k$, corresponding to the calculated exposures; $x_1, x_2, \ldots x_k$, was obtained by the procedure described above. The data were fitted by a least-squares line through the origin. The least-squares estimator b for the true value β is given by

$$b = \frac{\sum x_i y_i}{\sum x_i^2} \tag{C-4}$$

where the summation symbol implies summation over i from one to k. To use the regression line in reverse, i.e., to determine the true exposure ξ from some new observation y', the observed reading is divided by the slope b. An estimate of the standard deviation s_ξ, is obtained from

$$s_\xi^2 = \frac{1}{b^2} \left[\sum y_i^2 - \frac{(\sum x_i y_i)^2}{\sum x_i^2}\right]\left[1 + \frac{y'^2}{b^2 \sum x_i^2}\right]. \qquad \text{(C-5)}$$

Eqs. (C-4) and (C-5) are taken from Brownlee (24).

6.3.4 Results

A sample of ten 10-mR chambers was used to determine if the responses of individual dosimeters were different. Eight readings were obtained from each dosimeter at various exposure times. A regression line was obtained for each dosimeter, and the slopes of each were compared. There was no significant difference in the results. On this basis one regression line was obtained from the data from all chambers.

The responses of the TL-12 dosimeters were quite different from one dosimeter to the next. A separate regression line was determined for each dosimeter. The slopes of the various regression lines varied by as much as fifteen percent from the average of all 66 dosimeters.

Figures C-1 and C-2 show the precision which could be expected in the readings from both types of dosimeters.

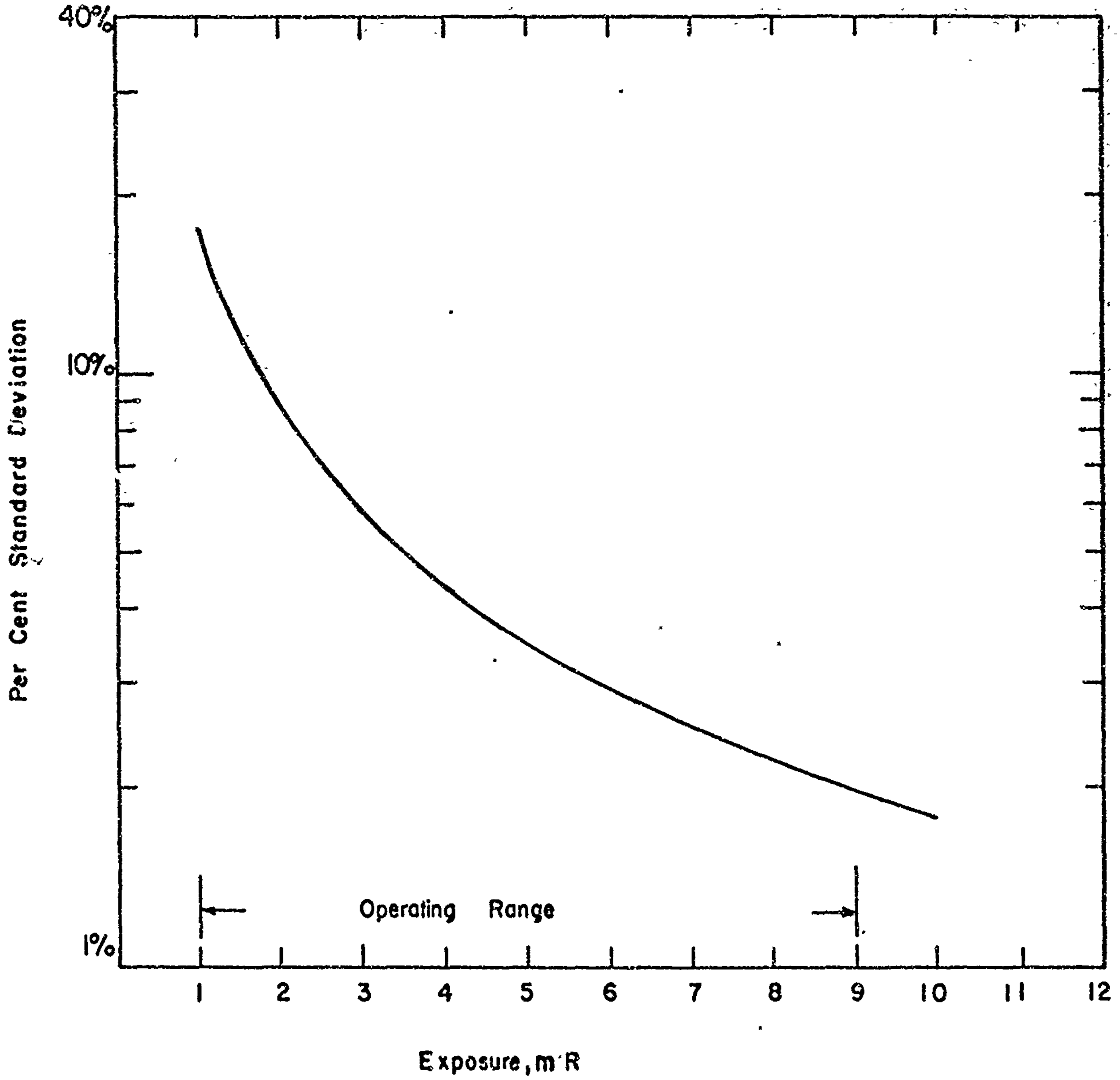


Fig. C-1. Observed precision for 10-mR ionization chambers.

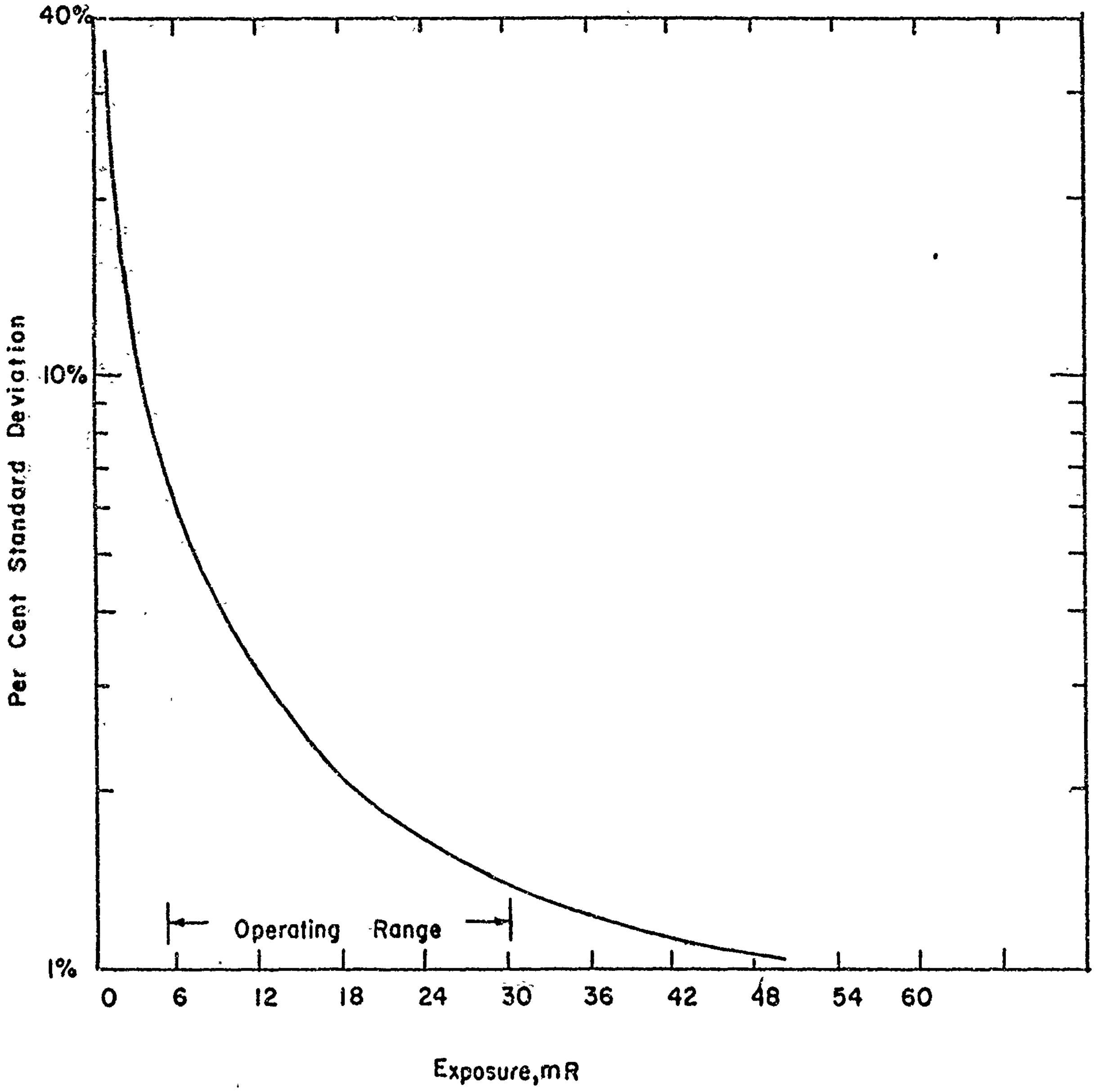


Fig. C-2. Observed precision for a typical TL-12 dosimeter.

6.4 APPENDIX D, Data Reduction and Statistics

This appendix details all steps used in the reduction of the data. The propagation of all significant errors is fully discussed.

A brief review of the experimental procedure is necessary in order to understand the data reduction process. Calibration curves (regression lines) were determined for the dosimeters as described in Appendix C. An experiment in the test house consisted of placing the dosimeters in the house, circulating the pumped source in one of the three tubing areas of the test field, and reading and recording the accumulated doses. Generally, each experiment, or run, was repeated three times for each tubing area.

The first step in the data reduction is to convert the reading from each dosimeter D_m to a corrected exposure D_c in milliroentgens. This is done by dividing the dosimeter reading by the slope b, from Eq. (C-4), of the regression line for the dosimeter. An estimate of the standard deviation s_{D_c} is determined from Eq. (C-5). For the 10-mR chambers, the reading D_m is first multiplied by β, from Eq. (C-1), to correct for the density of air at the time of the measurement. The corrected dose is then converted to a reduction factor Q, for one-quarter symmetry, according to the following formula:

$$Q = \frac{A}{S_p T} \frac{D_c}{D_o} \tag{D-1}$$

where A is the tubing area in square feet used in the run, S_p is the source strength in curies of the pumped source used in the run, T is the time in hours which elapsed while the source traversed the tubing area, and D_o is the reference dose rate. The value of D_o is taken to be 480×10^3 mR/hr for a point

located three feet in air from an air-ground interface at 22°C and 760 mm of Hg. The interface is the source plane with an intensity of one curie per square foot (6).

The factors A, T, and D_o are assumed to be without error. The fact that D_o may not be known accurately is irrelevant to the consideration of experimental errors. If one compares the results of these experiments with theory or with other experiments, the uncertainty in this factor is eliminated by normalizing both sets of data to the same reference dose rate. The corrected dose contains the factor S_c the calibration source strength, see Eq. (C-4), which has an associated standard deviation s_{S_c} which has not been included in s_{D_c}. Similarly the pumped source has an associated standard deviation s_{S_p}. These are systematic errors and should not be propagated along with the random errors in the intermediate steps of the data reduction. It should be noted that the factor S_c/S_p is present and separable in all succeeding values in the data reduction. The standard deviation, not including source uncertainties, for the value Q is

$$s_Q = \frac{A}{S_p\ T\ D_o} s_{D_c} \tag{D-2}$$

Since each experiment was repeated a number of times in the three tubing areas, the subscripts i and j are assigned to Q to differentiate the results of the various runs. The first subscript refers to the tubing area, while the second subscript refers to one of a series of runs from the same tubing area. Thus, Q_{ij} refers to the jth run in the ith tubing area. An average value $\bar{Q}_i$ is determined according to

$$\bar{Q}_i = \frac{1}{n} \sum_{j=1}^{n} Q_{ij} \tag{D-3}$$

where n is the number of times an experiment was repeated in the same area.

As an estimate of the standard deviation of $\bar{Q}_i$, one might use the formula

$$s'^2_{\bar{Q}_i} = \frac{1}{n^2} \sum_{j=1}^{n} s^2_{Q_{ij}}, \tag{D-4}$$

since $s_{Q_{ij}}$ is the estimate of the standard deviation on each value Q_{ij}. However, the only uncertainty used to obtain $s_{Q_{ij}}$ was s_{D_c} which is a measure of the randomness of the dosimeter readings in the calibration experiment. In the experiments in which values of Q_{ij} were determined, a number of new variables were introduced which were not controllable and may have varied from one run to the next. Generally, the results from runs in the same area agreed within the precision indicated by $s_{Q_{ij}}$. There was, however, in some cases such poor agreement among the Q_{ij} that the validity of the $s_{Q_{ij}}$ was suspect; i.e., cases where, say, in comparing runs k and l that $Q_{ik} + 2s_{Q_{ik}} < Q_{il} - s_{Q_{il}}$, or in other cases where $Q_{ik} + s_{Q_{ik}} < Q_{il} < Q_{im} - s_{Q_{im}}$. To account for the spread of the data in those cases, another term is added to $s'_{\bar{Q}_i}$ to give a better estimate of the standard deviation on the average:

$$s^2_{\bar{Q}_i} = s'^2_{\bar{Q}_i} + \frac{1}{n(n-1)} \sum_{j=1}^{n} (Q_{ij} - \bar{Q}_i)^2. \tag{D-5}$$

Reduction factors for full symmetry, R_i, are obtained by summing, over the symmetric points in each quadrant, the average values of the reduction factors for one-quarter symmetry. For a general off-center location, this sum is represented by

$$R_i = \bar{Q}_i^{NE} + \bar{Q}_i^{SE} + \bar{Q}_i^{SW} + \bar{Q}_i^{NW}, \tag{D-6}$$

where the superscripts differentiate the four quadrant points. For a location along the east-west or north-south centerline of the house, the following formula is used:

$$R_i = 2\ [\bar{Q}_i^N + \bar{Q}_i^S] \quad (R_i = 2\ [\bar{Q}_i^E + \bar{Q}_i^W]\ ), \tag{D-7}$$

where the superscripts differentiate the symmetric points on the respective centerlines. The full-symmetry value for a point along the vertical centerline is just four times the quarter-symmetry value. The estimates of the standard deviation $s_{\bar{Q}_i}$ are propagated accordingly to obtain s_{R_i}.

The method used to obtain the far-field reduction factor R_f and its associated standard deviation s_{R_f} is detailed in Appendix E. It should be noted that the ratio S_c/S_p can be factored from R_f, see Eqs. (E-2), (E-9), and (E-10). The total experimental reduction factor R_T is given by

$$R_T = R_f + \sum_{i=1}^{3} R_i, \tag{D-8}$$

and the estimate of the variance by

$$s_{R_T}^2 = s_{R_f}^2 + \sum_{i=1}^{3} s_{R_i}^2. \tag{D-9}$$

The estimate s_{R_T} indicates the precision of the experimental values. It may be used in comparing values from similar experiments using the sources S_c and S_p. However, if one wishes to compare these results with theoretical values or values obtained from experiments using different sources, the systematic

error in the source strengths must be included. The standard deviation in the final results, including the systematic errors, is labeled σ_{R_T} even though it is an estimate. This value is obtained from the preceding values according to the following derivation:

$$R_T = \frac{S_c}{S_p} \hat{R}_T \tag{D-10}$$

$$s_{R_T} = \frac{S_c}{S_p} s_{\hat{R}_T} \tag{D-11}$$

$$\sigma^2_{R_T} = R^2_T \left[\left(\frac{s_{S_c}}{S_c}\right)^2 + \left(\frac{s_{S_p}}{S_p}\right)^2 + \left(\frac{s_{\hat{R}_T}}{\hat{R}_T}\right)^2 \right] \tag{D-12}$$

$$= R^2_T \left[\left(\frac{s_{S_c}}{S_c}\right)^2 + \left(\frac{s_{S_p}}{S_p}\right)^2 \right] + s^2_{R_T}$$

All uncertainties quoted in this work refer to this value, σ_{R_T}.

6.5 APPENDIX E, Far Field Contribution and Associated Statistics

Since measurements could only be obtained from a simulated contaminated field of finite radius, the contribution from the contaminated area beyond that radius (to infinity) has to be estimated. This estimate is referred to as the far-field, or far-field contribution. The method of Kaplan (15) was used to obtain the far-field contribution. A basic description of this method and a means for estimating the uncertainty in the far-field are given here.

6.5.1 Theory

Kaplan's method is based on the equation

$$R_i = \alpha_D D_i + \alpha_S S_i \tag{E-1}$$

where R_i is the measured dose rate from the ith annular area in the contaminated plane; α_D and α_S are the structure attenuation coefficients for the direct and skyshine radiation, respectively; and D_i and S_i are the direct and skyshine free-field dose rates, respectively. A free-field dose rate is defined here as the dose rate that is obtained from an unshielded detector which is three feet above the center of the source annulus. These numbers can be obtained from theoretical calculations. Direct radiation refers to unscattered plus up-scattered radiation with respect to the detector. The structure attenuation coefficients are simply quantities which satisfy the equation. Although the quantities R_i, α_D, and α_S are functions of the detector position inside the structure, it is assumed that one particular location is under consideration; therefore no functional dependence is indicated.

The fundamental assumption of the method is that the quantities α_D and α_S are invariant with respect to the dimensions of the source annulus. Kaplan states that this is true as long as the separation between the source and the structure is greater than the dimensions of the structure. If one has measurements from at least two annular source areas, then, under this assumption the quantities α_D and α_S can be determined from Eq. (E-1). With these values the far-field contribution R_f is given by

$$R_f = {}_D D_f + {}_S S_f; \tag{E-2}$$

where D_f and S_f are the free-field dose rates from the far-field area.

If each term in Eqs. (E-1) and (E-2) is divided by the reference dose rate D_o, then α_D and α_S relate the measured reduction factors to the free-field reduction factors. In this work, reduction factors rather than dose rates are dealt with.

6.5.2 Calculations

The values α_D and α_S are computed from a system of three equations of the form of Eq. (E-1) corresponding to the three source annuli:

$$\begin{aligned} R_1 &= \alpha_D D_1 + \alpha_S S_1 \\ R_2 &= \alpha_D D_2 + \alpha_S S_2 \\ R_3 &= \alpha_D D_3 + \alpha_S S_3 \ . \end{aligned} \tag{E-3}$$

The left hand side of each equation has an independently determined variance $s^2_{R_i}$. In the determination of the variances of α_D and α_S, it is desirable to have a set of data in which all points have the same variance. Since one point with variance σ^2 is equivalent to n points with variances $n\sigma^2$, a set of weighting factors is obtained which will transform the system of equations into an equivalent set in which the left-hand side of each equation has equal variance. The weighting factor for the ith equation is given by

$$w_i = \frac{\prod_{i=1}^{3} s_{R_i}}{s_{R_i}} \tag{E-4}$$

The weighted equations are of the form

$$\hat{R}_i = \alpha_D \hat{D}_i + \alpha_S \hat{S}_i ; \tag{E-5}$$

where $\hat{R}_i = w_i R_i$, $\hat{D}_i = w_i D_i$, and $\hat{S}_i = w_i S_i$. The variance of each member of the left hand side of the weighted equations is

$$\hat{s}_R^2 = \prod_{i=1}^{3} s_{R_i}^2 \ . \tag{E-6}$$

In matrix notation the system can be written as $\bar{R} = \bar{\bar{A}}\,\bar{X}$; where $\bar{R}$ is the three-element vector of measured reduction factors, $\bar{\bar{A}}$ is the three-by-two matrix of free-field reduction factors, and $\bar{X}$ is the two-element vector of unknowns. The least squares solution of the overdetermined system is given by

$$\bar{X} = (\bar{\bar{A}}^T\,\bar{\bar{A}})^{-1}\,\bar{\bar{A}}^T\,\bar{R}. \tag{E-7}$$

The expressions for α_D and α_S, the elements of $\bar{X}$, can be written in terms of the elements of $\bar{\bar{A}}$ and $\bar{R}$ with the aid of the following definition:

$$\gamma = 1/\ [\ \sum \hat{D}_i^2 \sum \hat{S}_i^2 - (\sum \hat{D}_i\ \hat{S}_i)^2] \tag{E-8}$$

where the summation symbol implies summation over i from one to three.

$$\alpha_D = \gamma[\sum \hat{S}_i^2 \sum \hat{D}_i\ \hat{R}_i - \sum \hat{D}_i\ \hat{S}_i \sum \hat{S}_i\ \hat{R}_i] \tag{E-9}$$

$$\alpha_S = \gamma[\sum \hat{D}_i^2 \sum \hat{S}_i\ \hat{R}_i - \sum \hat{D}_i\ \hat{S}_i \sum \hat{D}_i\ \hat{R}_i] \tag{E-10}$$

From the principle of maximum likelihood, it can be shown that the variance of the estimators α_D and α_S are the diagonal elements of the matrix $(\bar{\bar{A}}^T\,\bar{\bar{A}})^{-1}$ times the variance $\hat{s}_R^2$ (25). Explicitly, these values are

$$s_{\alpha_D}^2 = \hat{s}_R^2\ \gamma \sum \hat{S}_i^2 \tag{E-11}$$

$$s_{\alpha_S}^2 = \hat{s}_R^2\ \gamma \sum \hat{D}_i^2. \tag{E-12}$$

The estimate of the far-field is then determined from Eq. (E-2). The variance of R_f is obtained by propagation of the s_{α_D} and s_{α_S}:

$$s^2_{R_f} = D^2_f\, s^2_{\alpha_D} + S^2_f\, s^2_{\alpha_S}. \qquad \text{(E-13)}$$

The free field reduction factors were determined from moments method calculations of Rubin (18). The numbers used are tabulated below:

Annulus	Inner radius	Outer radius	D	S
1	19'*	80'	0.2513	0.007662
2	80'	125'	0.07246	0.005791
3	125'	169'	0.04608	0.005381
f	169'	∞	0.2017	0.06433

Using the data from the first tubing area apparently violates the condition that the source should be a distance away from the structure at least as large as the dimensions of the structure. However, after some initial calculations, it was decided that the inclusion of this data helped to balance the effects of random errors in the data from the second and third areas. Two sets of the values α_D and α_S were computed for a number of detector locations. One set was determined from the first two equations of Eqs. (E-3), while the other set was determined from the last two equations of Eqs. (E-3). The discrepancies between the two sets of values seemed to be random which indicated that no systematic error was introduced by including the data from the first area. However, had the outer radius of the first tubing area been less than about 40 feet this may not have been the case.

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*Since, in the actual test field, the inner boundary of the first tubing area was a 30' x 40' rectangle, an effective radius for this area was determined. It was defined as the radius of the disk which subtends the same solid angle as the rectangular area at a height of three feet above the center.

The method used in estimating the far field contribution is not without difficulties. It was found in this work that in several cases the structure attenuation coefficients determined from the least squares analysis of the data were negative or larger than unity. Those detector locations which were above grade but still below the basement ceiling presented the most problems. It is felt that the method is very sensitive to small fluctuations in the measured exposure rates. This may be seen by inspecting the algebraic expressions for the structure attenuation coefficients which result from the least squares formulation (equations E-8 through E-10). Both the numerator and the denominator of the expressions are very likely to be the difference of two relatively large numbers, which will result in a very significant loss of accuracy and may also result in physically unrealistic coefficients.

In some cases in this work the structure attenuation coefficients were such that a negative far field estimate was calculated. In order to try to avoid this situation the following procedure was adopted. Initially all three tubing areas were used in the analysis as previously discussed. If a negative far field estimate was calculated the result was rejected and a new calculation was performed using only the outer two tubing areas in the analysis. This calculation is not least squares, but merely the solution of two simultaneous equations in two unknowns. Standard deviations were calculated using normal propagation of error techniques. In some isolated cases this second calculation did not correct the situation. In these cases an attempt was made to estimate the far field contribution on the basis of the estimates calculated at other similar detector locations or on the basis of calculations made at surrounding locations. Little confidence can be placed in these estimates as evidenced by the associated standard deviations.

It should be noted that out of the nearly 350 data points presented in this work about 12 percent of them had negative far field estimates after the first calculation. After the second calculation only about ten data points had negative far field estimates. It should also be noted that no experimental data are presented for Houses 15, 16, 17, and 18 since it is felt good estimates of the reduction factors can be obtained from the data for the corresponding "thin walled" experiments, as evidenced by comparing Houses 1 and 12 for instance.